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CONTENTS

Number 21

P. H. CARPENTER: The Application of Science to Modern Tea Culture 1

W. B. HAINES: Manuring *Hevea*. II. Revision of Experimental Results by means of a Sampling Method for Yield . . . 11

L. C. SNOOK: Cereal Grains as a Source of Nutritionally Useful Phosphorus 20

M. FINCI: The Relation between Body-conformation and Productivity in the Cyprus Fat-tailed Sheep 25

A. H. LEWIS: The Relative Values of Organic and Inorganic Nitrogen Fertilizers 38

F. CROWTHER and M. S. BARTLETT: Experimental and Statistical Technique of some Complex Cotton Experiments in Egypt 53

W. M. ASHTON: The Chemical Composition of the Grain and Straw of Varieties of Oats Bred at the Welsh Plant Breeding Station: Comparison with some Older Varieties . . 69

W. GODDEN and S. C. RÂY: Dicalcium Phosphate and Steamed Bone-flour as Supplements for a Phosphorus-deficient Ration 79

J. L. STEWART: The Cattle of the Gold Coast. With Plates 1, 2 . 85

D. SIMPSON and T. SMALL: The Potato Industry in Jersey. With Plate 3 95

Number 22

W. J. HALL: Citrus Cultivation in Southern Rhodesia. With Plates 4, 5 101

M. H. FRENCH: Development of Live Stock in Tanganyika Territory. II. Tanganyika Breeds of Sheep, and Mutton Qualities of the Long-tailed Type and its Crosses with Black-headed Persian Sheep 112

MARGARET NEWTON: The Cereal Rusts in Canada 125

W. H. CASHMORE: Mechanization of the Small and Medium-sized Farm in Great Britain. With Plates 6, 7 141

W. E. J. MILTON: The Effect of Irrigation on the Palatability of certain Grass and Clover Species grown in Plots of Pure Species 150

W. G. COCHRAN: Some Difficulties in the Statistical Analysis of Replicated Experiments 157

O. W. R. DENT, A. D. MANSON and D. TREVAINS: The Relative Values of Organic and Inorganic Fertilizers for Hops in Herefordshire. 176

F. E. ROWLAND: Electric Soil-heating. With Plate 8 . . . 179

T. BELL: Preliminary Work on the Artificial Insemination of Live Stock in Palestine 188

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XUM

Number 23

J. ANDERSON: Artificial Insemination of Cattle and Sheep in Kenya. With Plate 9 193

J. EDWARDS and A. WALTON: A New Service-crate. With Plate 10 206

F. W. ANDREWS: Investigations on Black-arm Disease of Cotton under Field Conditions. III. The Mode of Infection of the newly planted Crop 207

E. E. CHEESMAN: Recent Botanical Researches in Cacao . 219

R. O. Williams: The Citrus Industry in Palestine 225

BRYNMOR THOMAS and F. E. MOON: A Preliminary Study of the Effects of Manurial Treatment, and of Age, on the Carotene-content of Grass 235

M. H. FRENCH: Development of Live Stock in Tanganyika Territory. III. Skeletal Measurements of Local Fat-tailed and Grade Black-headed Persian Sheep 246

D. H. FINDLAY and E. T. SYKES: Influence of Size of Seed and Spacing on the Yield of King Edward VII Potatoes . . 253

J. B. E. PATTERSON: Some Observations on a Disease of Sheep on Dartmoor 262

SIR E. JOHN RUSSELL and D. J. WATSON: The Rothamsted Field Experiments on Barley, 1852–1937. A. The Older Rothamsted Experiments. B. The Modern Rothamsted Experiments. . 268

Number 24

SIR E. JOHN RUSSELL and D. J. WATSON: The Rothamsted Field Experiments on Barley, 1852–1937. Pt. II. Effects of Phosphatic and Potassic Fertilizers. Deterioration under Continuous Cropping 293

G. A. COWIE: The Relation of Phosphatic Manuring to Potash-deficiency Symptoms on the Potato Crop 315

A. H. H. FRASER and W. THOMSON, and D. ROBERTSON and W. GEORGE: The Influence of the Nutritional Condition of Lambs on their Susceptibility to an Artificial Infestation with Parasitic Nematodes 316

D. D. PATERSON: Further Experiments with Cultivated Tropical Fodder Crops 323

H. P. DONALD and I. FLEMING: The Effect of Prenatal Weight-changes in Breeding Sows on the Number and Size of Newborn Pigs 341

R. CECIL WOOD: Experiments on Compost-making . . 350

WILLIAM DAVIES and T. W. FAGAN: Winter Keep on Temporary Leys 369

E. L. TAYLOR: Parasitic Diseases of Farm Animals . . 377

THE APPLICATION OF SCIENCE TO MODERN TEA CULTURE

P. H. CARPENTER

(*Chief Scientific Officer, Indian Tea Association*)

The Pre-scientific Period

IN the early days of the tea industry, methods employed in tea culture were either haphazard or rule of thumb. In practice, the methods of plant-growing used in temperate climates were adopted generally by the tea-grower with little or no modification, and this could hardly have been otherwise because in those days there was no scientific agricultural research in countries where tea was being grown. For instance, it was not until the early part of this century that an agricultural department was brought into being in India.

Tea was planted out in the early days on land cleared from forest, as this was recognized to be the best land for tea. It was, however, very quickly realized that the development of the tea plant was greatly furthered by cultivation, which resulted in keeping the land clean of weeds and at the same time in stirring the soil (the cultivation was done by manual labour using hoes). This method gave such good results that for many years the only treatment that was said to be required for tea was 'tincture of steel'. Such methods, of course, very quickly rendered soluble a large part of the soil nitrogen. Undoubtedly the tea plant made use of the abundant supply of soluble food, but a very large amount was certainly wasted. For many years these practices appeared successful, and there seemed to be little or no need to study other methods. Eventually soil deterioration began to be evident, for such methods resulted in the soils losing their fertility until they approached a certain low level of crop-production, approximating in North-East India to 400 lb. of tea per acre per annum. This crop removes from the soil about 20 lb. of nitrogen, 4 lb. of phosphoric acid, and 10 lb. of potash annually, and it seems that tea soils of North-East India are able to maintain this standard of fertility almost indefinitely.

Manuring was not practised except in a very few cases where cattle manure or the rich surface-scrapings from water-courses were used for top-dressing. Knowledge concerning pruning and plucking was so indefinite that every planter might be said to have had his own ideas, which probably differed considerably from those of his fellows. Pests, although recognized, were largely uncontrollable, for nothing was known of their life-histories. In those early days it was barely recognized that tea suffered from disease. It is now difficult to realize the lack of knowledge under which the early planters laboured, and that there was practically no reliable information available to them upon any subject connected with tea culture.

The Scientific Period

Tea, however, developed fairly satisfactorily under such conditions, though as early as 1886 the tea industry in Java realized that there was

need of scientific study, and Dr. Lohmann was appointed to carry out investigations under the direction of Dr. T. van Romburgh. The first report appeared in 1894. In 1898, Mr. M. K. Bamber began his study of the tea soils of Ceylon, but it was not until 1924 that the plans for a Tea Research Institute in Ceylon were finally approved. In 1926, Mr. Petch was appointed as the first Director of the Tea Research Institute in Ceylon.

At the end of the last century the tea industry was experiencing a very severe and prolonged depression, and it became increasingly difficult for tea companies in North-East India to maintain their position. In these conditions, and somewhat as a last resort, the Indian Tea Association sought the aid of science in the solution of some of its difficulties. The appeal, I fear, was made in a very sceptical frame of mind: there was doubt whether science could teach practical planters anything.

At the end of 1899, by the advice of Dr. J. A. Voelcker, H. H. Mann, who was then working at the Woburn Experimental Station in England, was appointed Scientific Officer to the Indian Tea Association; and in 1909, R. D. Anstead was appointed Scientific Officer to the United Planters' Association of Southern India.

The very successful work of the early investigators soon convinced the tea industry that science could give valuable assistance, and since the initiation of scientific investigation this work has steadily developed. To-day there is the Thee Proefstation in Buitenzorg, Java, the Tocklai Experimental Station in North East-India, the Tea Experimental Station at Nellakota in South India, and the Tea Research Institute in Ceylon. Both Japan and Russia are also maintaining institutions for the scientific study of tea culture. The need of scientific investigations has steadily increased, so that each of these institutions now has a staff specialized in all or most of the following branches: agricultural, bacteriological, botanical, chemical, entomological, and mycological.

The adoption of scientific methods by the tea industry may be said to have begun about the beginning of the present century. Although the members of the Indian Tea Association may have been sceptical of the aid they might get from science, yet having once made the appointment, they adopted the liberal and truly wise policy of giving the scientist a free hand in his investigations. Mann, studying the problems of North-East India, quickly realized that one of the main troubles was the loss of soil fertility and the inability of the deteriorated soil to supply the necessary quantity of nitrogen to the bushes. He was fortunate to find rape-seed cake available locally and very cheap in many of the tea-growing districts in North-East India. This oilcake was made as a village industry in hand-powered mills. The percentage of oil left in the cake was high and that of nitrogen low, amounting in general to about $4\frac{1}{2}$ per cent. in good samples. Applications of this cake were made at the rate of 400 lb. per acre, and the response of the tea bushes to this treatment was most encouraging. This may be regarded as the start of the systematic use of nitrogenous fertilizers for tea, and since then the consumption of manures has increased steadily wherever tea is grown. For a long time only such fertilizers as oilcake and cattle manure were used, but gradually

other materials, such as fish, sterilized animal meal, and various kinds of oilcake came into use.

A still further development was the growing of leguminous crops amongst the tea as a green manure both for enriching the soil with nitrogen and for improving its tilth. A further extension of this method of adding nitrogen to the soil has taken the form of growing leguminous trees, such as *Albizzia stipulata*, *Albizzia moluccana*, *Lucaena glauca*, amongst the tea.

Manuring.—The manures that were used contained nitrogen in an organic form and it was not until some field experiments conducted by the Scientific Department of the Indian Tea Association had demonstrated that nitrogen in the form of soluble 'minerals' such as nitrate of potash, nitrate of soda, and sulphate of ammonia was able to give good results that any attention was paid to the non-organic manures. Whilst the value of these manures became increasingly evident, there was a very strong prejudice, which exists to a small extent even to-day, against the use of inorganic forms of nitrogen. Fully replicated field experiments in all the tea-growing countries have, however, demonstrated the value of nitrogen in the inorganic form of sulphate of ammonia. At Tocklai replicated field experiments have now been carried on for over 17 years in which the same kind of manure has been added annually to the same plots. The results show that sulphate of ammonia, if used to supply an equal quantity of nitrogen, gives results as good or better than those obtained from organic manures such as oilcake, cattle manure or green manure, or cuttings of leguminous plants (e.g. *Tephrosia candida*).

It is often maintained that cattle manure is valuable not only because it supplies nitrogen but also because of its bulk of organic material. Experiments carried out at Tocklai have shown that over a period of 4 years an annual application of 5 tons of cattle manure supplying 60 lb. of nitrogen has given an increase of 765 lb. of tea per acre, whereas in another experiment an annual application of 60 lb. nitrogen as sulphate of ammonia has given over the same 4 years an increase of 1,580 lb. of tea per acre. Similar results have been obtained in other experiments, indicating that for the same application of nitrogen, cattle manure possesses about one-half to one-third the efficiency of sulphate of ammonia. It is sometimes claimed that cattle manure is slow-acting and that its effect will be felt over a large number of years. Actual trial, however, shows that one application of 20 tons per acre of cattle manure containing 160 lb. of nitrogen produces a crop-increase over 4 years, but for no longer. An application of an equal quantity of nitrogen as sulphate of ammonia gives about double the increase in crop over the same period of time. It does not, therefore, appear from these experiments that cattle manure is an efficient manure, nor does it give increases of crop over any long period of time.

Nitrogenous manures seem to give an increase in crop proportional to the amount of nitrogen supplied:

Nitrogen applied annually	*Average annual gain in crop in lb. of tea per acre*
lb.	*lb.*
40	256
80	535
120	721

The crop-increase obtained is proportional to the amount of nitrogen that becomes quickly available to the tea plant, and a slow-acting manure is generally synonymous with an inefficient manure. The amount of increase obtained per lb. of nitrogen applied varies with the soil and other conditions. Broadly speaking, the higher the natural cropping capacity of the soil the less the response from nitrogenous manuring.

Place	*Crop increase in lb. of tea per acre per lb. N for doses of 40 lb. N per acre per annum*
	lb.
Tocklai (Assam)	6·4
Tulsipara (Bengal, Dooars)	5·1
St. Coombs (Ceylon)	4·4

For a certain quantity of nitrogen added annually to the soil the tea crop will increase until it reaches a certain maximum dependent upon the amount of nitrogen added annually. This rise to a maximum does not take place at once; there is a steady increase, which at Tocklai with an application of 40 lb. of nitrogen reaches a maximum in about the fifth year of continuous manuring. On experimental plots the increased crop in lb. of tea per acre for an application of 40 lb. of nitrogen per acre is:

First year,	3·3	lb.	crop	per lb. nitrogen
Second year,	5·0	,,	,,	,,
Third year, Fourth year,	6·4	,,	,,	,,
Fifth year,	8·0	,,	,,	,,

It has been argued that the use of a manure giving soluble nitrogen slowly throughout the year, or the application of a soluble manure in small doses at intervals during the year, would be likely to give better results than one big application of a soluble manure once in the year. Experiments have shown, however, that where manuring is carried on systematically every year, and the same method of application is used, the crop return for tea is the same whether a soluble manure like sulphate of ammonia is given in one application or in divided applications, and this is true for such large annual applications as 600 lb. of sulphate of ammonia, supplying 120 lb. of nitrogen per acre.

Annual application	*Total crop of tea per acre in 7 years*
	lb.
120 lb. of nitrogen applied in one dose in March	8,856
120 lb. of nitrogen in three equal parts, March, May, and July . . .	8,856

On the acid soils suitable for tea in the plains of North-East India, experiments at Tocklai have shown that a soluble manure like sulphate of ammonia, if broadcast over the soil in the spring, gives the same crop-increase whether it is left exposed on the soil surface or whether it is turned in by light cultivation.

A commonly expressed opinion, backed however by no evidence, is that the continual use of a manure, such as sulphate of ammonia, to tea results eventually in the depletion of organic matter in the soil. Such opinion has strongly advocated the use of bulk organic manures for tea. An experiment that has now been continued for 17 consecutive years compares the effect of sulphate of ammonia with that of cuttings from *Tephrosia candida* supplying an equal quantity per acre of nitrogen. So far no advantage is shown from the use of the bulk manure in the condition of either tea bush or soil. Throughout the experiment sulphate of ammonia has proved superior and still continues to do so.

An important experiment has shown that the use of sulphate of ammonia continued annually has resulted in an increase of soil nitrogen and organic matter varying with the amount of sulphate used.

Fertilizer nitrogen applied annually over 7 years	*Loss on ignition of dry soil (organic matter)*	*Nitrogen in dry soil*
lb.	%	%
0	2·80	0·094
40	2·93	0·096
80	3·09	0·101
120	3·10	0·104

The supposition that the use of 'artificial' nitrogen on tea soils 'exhausts' the soil of organic matter and nitrogen is the reverse of the truth. These results may at first seem somewhat surprising, but a little knowledge of tea culture permits a simple understanding of the facts. Tea bushes are planted about 4½ ft. apart, and by pruning and plucking are maintained at a height of about 3 ft. to 4 ft. from the ground. During the year new growth develops, part of which is removed by plucking; most of the remainder is buried at the next pruning. In North-East India, and in the particular instance under consideration, the pruning was done annually, and the weight of prunings which were turned into the soil increased with the weight of manure used.

Nitrogen applied annually over 7 years	*Dry weights of prunings*
lb. per acre	tons per acre
nil	1·0
40	1·5
80	2·0
120	2·3

With the increased doses of nitrogen there is an increased growth of bush, and consequently an increased weight of prunings that are returned to the soil. The prunings, whether from very heavily manured or from unmanured plots, had the same composition. Such prunings provide an annual addition of organic matter to the soil which in decomposing is able to render at least a part of its nitrogen available to the bush. Part, however, remains unavailable and accumulates in the soil. Whether the prunings are buried with or without the addition of soluble nitrogen appears to make no difference to the crop return that is obtained, beyond

that which would be expected from the additional soluble nitrogen. In other words there is no interaction between the effects of prunings and the sulphate of ammonia so far as nitrogen supply is concerned. It would seem that nothing would be gained by composting such material, a procedure that has been much advocated of late. These results make it clear that at any rate for tea culture there need be no fear that the use of an inorganic manure, such as sulphate of ammonia, will deplete the soil of organic matter so long as the tea prunings are incorporated in the soil. It would also seem that the incorporation of this weight of organic matter as prunings into the soil is sufficient for the soil's requirements, and consequently no gain in crop is obtained by the use of bulky organic manures.

The use of a phosphatic manure, either alone or in conjunction with other manures, has so far been found to have but little effect upon the tea crop. Experiments at Tocklai have shown a very slight improving effect upon the quality of the tea made. The use of potash as a manure has had no influence on the crop, but has an interesting effect upon the quality of the tea. Experiments made in North-East India show that potash causes a slight loss in quality, but at St. Coombs in Ceylon it tends to improve the quality of the tea. These apparently conflicting results may be due to the difference in the amount of potash in the tea leaves at the two places.

Place	*Percentage of potash in dry green leaf*
Tocklai (Assam)	2·65
St. Coombs (Ceylon)	1·60

In order that tea may flush vigorously, an acid soil is required, and the optimum range of acidity varies according to the nature of the soil. For instance, in North-East India tea grows vigorously

on a sandy soil with a pH of 5·8 or less,
on a clay soil with a pH of 5·2 or less,
on a peat soil with a pH of 4·8 or less.

The use of sulphate of ammonia has in many instances given a greater crop-increase than was to be expected from the amount of nitrogen applied. Such additional crop-increase is attributed to the acidifying effect of the fertilizer upon the soil. The sulphate of ammonia causes the colloidal soil particles to coagulate, thus imparting to the soil a more open texture. This effect is noticed after a comparatively few years' application of sulphate of ammonia in small dressings, such as 150 lb. per acre.

Scientific knowledge concerning the manurial treatment of tea is now considerable and has much influenced modern methods of tea culture, more particularly during the recent years of severe financial depression. Experiments have shown that the tea crop and also the quality of the finished tea can be maintained by the use of moderate annual applications of nitrogen only, which can most efficiently be given in the form of sulphate of ammonia, up to a maximum of 300 lb. per acre, without

noticeably affecting the quality of the tea made. This result has made it possible to reduce the cost of manuring programmes by 25 per cent. or more, a very valuable saving under conditions that impose strict economy.

Cultivations.—Most soil-cultivation methods have been tried for tea, but largely without adaptation to particular conditions. The type of cultivation has varied between deep cultivation with soil stirring practically every month during the growing season, to hand-weeding with no soil stirring. All the various methods have been claimed as being highly successful. Careful experiments have, however, brought to light certain facts. On the flat land of Tocklai the tea crop varies with the suppression of weed-growth: soil stirring apart from weed-suppression has little effect upon the crop.

	Treatment	*Crop of dry tea* lb. per acre
A	Soil turned 7 times in growing-season by manual labour	1,600
	Hand-weeded 4 times in the season: no soil stirring	1,592
B	Soil surface scraped 5 times without stirring	843
	Soil lightly stirred to a depth of 3 in. 5 times	809

In another instance the plots are maintained as nearly as possible at equal cost, one being cultivated by manual labour seven times in the year and receiving 200 lb. of sulphate of ammonia; the other receiving one cultivation in cold weather and one cultivation in the growing-season only, together with 400 lb. of sulphate of ammonia.

Two soil stirrings 400 lb. sulphate of ammonia	1,208 lb. of dry tea per acre.
Seven soil stirrings 200 lb. sulphate of ammonia	824 lb. of dry tea per acre.

These results show that for tea (a perennial crop) annual soil stirring does not appear to be necessary. Soil stirring provides a good seed-bed for weeds, which develop more on cultivated land than on land with undisturbed soil. Further, tea roots penetrate throughout the surface-soil if it is left undisturbed, and so suppress the growth of weeds. In such conditions the tea bushes develop so vigorously that they touch each other, covering the ground completely, so that weed-development is very greatly hindered by the exclusion of light. It is hence possible on flat land to reduce cultivation costs to a very low figure, if this is combined with suitable nitrogenous manuring to produce large bushes that give a dense shade over the soil; at the same time a maximum crop is obtained. By adopting such methods for keeping the land free of weeds, labour costs are greatly reduced, and so also is the cost of production of the tea. Cultivation as now practised aims at supplying the soil with soluble nitrogen in form and quantity suitable to the requirement of the plants, and without the waste that accompanies unnecessary soil stirring. In practice this principle is necessarily adapted to suit varying conditions. Although such a method as hand-weeding and the entire suppression of weeds can be practised satisfactorily on flat land, it has been found to result in soil erosion on slopes. Hence this form of cultivation has been

modified, in that selective weeding is practised, leaving only those shallow-rooting plants that are thought to be least deleterious to the tea, which in some cases amounts in practice to the removal of all grass-roots whilst leaving other weeds. A first consideration in both these methods is that the tea bushes shall so cover the ground as to protect the soil from direct light and rainfall.

Variety and quality.—Tea is planted out from seed collected from many sources, but the first tea-gardens were established with plants brought directly from China, or from seed imported from China. Subsequently tea was found growing wild in Assam, which was at first thought to differ so greatly from the Chinese variety that it was unlikely to make commercial tea. This view was, however, disproved, and it is from this source that the modern tea-gardens have developed. Seed from Assam has been sent to the other tea-growing countries, and these in their turn have developed their own seed-gardens. The original seed of the Assam type was collected in the jungles and was used for making seed-gardens. Owing to carelessness and ignorance of methods likely to ensure effective selection, there exists to-day no commercially known pure-line variety of tea. The progeny from all seed-gardens is much hybridized, and it is evident to any casual observer that the plants raised from any one seed-garden give progenies which differ considerably amongst themselves in appearance. Experiments have shown also that the characteristics of the tea manufactured from individual bushes differ considerably. In a broad way it is recognized that certain kinds of tea-plant are suitable for certain cultural and climatic conditions, but even so, the variation found among plants from any commercial type of seed is likely to be as great as that between the commercial types themselves. Very great improvement would result if uniform characteristics could be achieved in the product from any one seed-garden.

In the Netherland East Indies much work has been done in the direction of selecting bushes for some desirable quality and vegetatively reproducing such bushes by budding. The Botanist of the Thee Proef-station, Java, has now a number of such clones undergoing trial. Of more recent years intensive work has been begun in Russia along the same lines, employing either budding or cutting as the method of vegetative reproduction. Particular attention in this case has been paid to the development of frost-resistant strains. Tunstall, at Tocklai, undertook experiments on the production of tea bushes from cuttings, but no systematic work was possible in the absence of a botanist, and it was not until 1930 that one was appointed. Since then work in this direction has been in progress. Attention is also being paid to selection work in Ceylon. This work is in its early stages and has not yet been developed commercially. In Java, however, one seed-garden raised by budding is to-day established and yielding seed.

It is in the direction of variety selection and the production of uniformity in the progeny of tea seed-gardens that the next big development in tea culture is likely, and indeed might almost be said to have begun, for the importance of research in this direction is now recognized throughout the industry.

Pests and diseases.—In no part of tea culture has scientific investigation had a greater effect than in the recognition and control of pests and blights. Before scientific investigation came to tea, little or nothing was known concerning insect pests, except that they were doing damage. With a careful investigation of the life-histories of the various pests, satisfactory control measures have been established for nearly all the more dangerous pests. The necessity for continuous attention to control measures is not yet adequately realized, so that every now and again an epidemic outbreak becomes serious for a while until control measures are once more in full operation.

The recognition that root-disease often causes the death of bushes has resulted in the adoption of methods to prevent it from spreading, and whilst such diseases still occur they are no longer responsible for the very heavy loss of bushes that were formerly due to this cause. The study of disease-organisms has greatly reduced the casualties.

Leaf-diseases are controlled by systematic spraying and pruning. The disease that enters through pruning-cuts is still a difficult and as yet an unsolved problem, for whilst it is probably unnecessary and certainly impossible on a practical scale to treat pruning-cuts in the ordinary course of annual light pruning (there are about 4,000 bushes to the acre), the heavier type of pruning, which is done at intervals of 10–15 years low down on the framework of the bush, does need attention. No entirely practical method for protecting the large cuts made at this operation has yet been found. The best remedy lies in the abolition of such forms of pruning, and this has already done a great deal towards maintaining the health of bushes. A problem that is still serious is how to treat rotting pruning-cuts on old bushes; so far no satisfactory solution has been found.

Manufacture.—The general process of tea-manufacture has undergone but little change, except in improvements and modifications in machinery. Three theories of tea-fermentation have received attention: (1) it is a purely chemical reaction; (2) reaction depends upon the presence of enzymes naturally present in the tea-leaf, or (3) on enzymes that exist in the cells of micro-organisms but not in the cells of the tea-leaf.

As long ago as 1891, Kozai, in Japan, suggested the importance of micro-organisms. Later workers, however, favoured the enzyme theory, but it was not until Dr. Bernard in 1911 published his investigations that any certain knowledge of the micro-organisms that might be associated with tea-manufacture became available. No further development of this work took place until a bacteriologist was appointed at Tocklai. For a long time it has been evident that none of the three theories can satisfactorily explain happenings in factories, but now it is appreciated that both enzymes of the tea plant and the enzymes of micro-organisms may be active in tea-factories. This has led to a detailed study of the organisms present, and in North-East India there is probably no factor having a greater influence upon the general improvement of tea than the realization of the ill effects that the uncontrolled development of micro-organisms in factories may have. Mann insisted, without detailed knowledge, upon the necessity for aseptic conditions in tea-factories, but only of recent years has it been appreciated that certain unfavourable tea characteristics

which very commonly developed, particularly during the hot, wet months of the year, are not inherent in the process of tea-manufacture, and that they can and should be eliminated.

Scientific investigation has not yet developed to such an extent that a tea can be judged upon its chemical analysis, though chemistry has revealed the important fact that the constitution of the tannin found in tea differs from that of digallic acid (the tannic acid of the British Pharmacopœia). This discovery is of much importance, for it is no longer permissible to attribute the physiological reactions of digallic acid to the tannin of tea. This has often been done in the past by medical men, and has led to much misrepresentation in regard to tea-drinking.

(*Received October 18, 1937*)

MANURING *HEVEA*, II. REVISION OF EXPERIMENTAL RESULTS BY MEANS OF A SAMPLING METHOD FOR YIELD

W. B. HAINES

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Summary.—A new system of recording yields by a sampling method has been introduced in the Dunlop manurial experiments on rubber, which has improved the reliability by avoiding certain human sources of error and has increased the amount of detailed information obtained. The first revision of one set of experiments previously described in this *Journal* indicates that the complete fertilizer has usually a significant superiority over nitrogen alone—a result which was not supported in the conclusions formerly expressed.

Introduction.—In a former paper Haines and Guest [1] gave a summary of recent experimental results from manuring *Hevea*. One comment there made has assumed a special significance in the light of subsequent investigations, namely, the remark that there was sometimes a hardly credible contrast between a good improvement in the appearance of the trees and the poor improvement reported in the yields. The time-lag between general vegetative improvement or deterioration and the attainment of improved or deteriorated bark in the tapping-cycle accounts for a good deal of this discrepancy between appearance and performance. However, when a new recording-system, based upon sampling methods, had to be instituted for new experiments falling under contract tapping, the opportunity was taken to test any doubts concerning the reliability of the older method of recording. It was revealed at once that accuracy had been rather variable, and that most of the apparent inconsistencies disappeared in the revision of results. Since the new method was more sensitive and more reliable, besides being more flexible and giving much more detailed information, it was at once generally adopted.

Old method.—The older method had been designed with the main object of fitting in with ordinary estate routine. Plot-sizes were arranged to correspond with tasks, so that no special arrangements would be necessary for collecting. Tappers carried in their own crops as usual, and the routine recording of latex at the factory was elaborated by bulking latex from the same treatments and sampling for dry-rubber content to give true yields. The weakness of the system appears to have lain in trusting the collecting and carrying to the tappers, for they have no appreciation of the experimental requirements and are unlikely to inconvenience themselves. Mixing for mutual help in carrying, for instance, is a common practice, which may be prohibited but cannot with certainty be prevented. The process of tapping is also one which lends itself to adaptations of skill, the differential application of which to the plots must be avoided, for it is apt to be practised either to meet the (assumed) desires of the experimenter, or to produce an appearance of commercial uniformity.

New method.—In the new method an independent proportional random sample of trees is taken on certain days, and the yields are recorded by a special man who coagulates the latex in the cup and carries out the collection, preparation, and weighing of the rubber 'biscuits'. Estate organization of tapping is not interfered with, and in new experiments plot-sizes can be chosen as small as desired. Dyes in the coagulant are used to assist in distinguishing samples from different plots, and the small, numbered, wooden spring-clips that are placed on the cups of trees upon which the lot falls are transferred to the biscuits and serve to preserve their identity. Preliminary examination of the statistics by the method of Yates and Zacopanay [2] showed, for a plot-size of 200 trees, that satisfactory accuracy is obtained in budded rubber if the lot is chosen to fall on one tree in fifteen (giving over 70 per cent. of the information derived from complete harvesting), whilst in seedling rubber one needs to take one tree in seven or one in five, giving a recovery of 50 to 65 per cent. of information. Blocks of treatments are dealt with in one day, so that day-to-day change (weather) is eliminated with blocks in the analysis. Since the recording is repeated at intervals that are small compared with the rate of natural change, the method is obviously quite efficient for experiments which have themselves an ineluctable plot-error of 10 per cent. or so of the mean. Agreement between successive measurements of the same plots in the same season, or between duplicate independent samples taken by two men on the same day (e.g. an instructor and a learner), has proved remarkably good. Correlation coefficients between 25 or 27 pairs of such plot values have never been less than 0·83, and have sometimes exceeded 0·96. Readings taken at seasons of abnormal yields or rapid change, such as occur at wintering, cannot be taken as representative, but it may be remarked that the method, by giving individual tree-yields, is eminently suited for following through the interesting details of yield-reactions during such periods. The early results suggest that there are marked differences in the reactions of manured plots under changing weather conditions. 'Complete inorganic' plots, for instance, keep up their yield best in dry spells, which suggests that structural improvement in the trees may be quite as marked below ground as above ground, so influencing moisture-supply.

Character represented by distribution-curves.—The data so collected give interesting means of characterizing various stands of rubber. The sets of samples of 15, 20, or 25 trees from similar plots may be set out in order of magnitude, and the average calculated for each position from best to worst, so giving curves of the kind shown in Fig. 1. This form of smoothing has been chosen as more easy for comparisons of limited data than the usual distribution-histogram showing sizes of yield-groups. The standard form of distribution-curve is always very skew for rubber-yields, the mode being from one-half of the mean to as low as one-fifth. Curves 1 and 2 are for young buddings, the flattening of the curve for the older stand illustrating how uniformity improves with time. The sagging at the lower end of Curve 1 is due to smaller trees which have gradually been brought into tapping after the others. Curve 3, by its steepness, illustrates the greater variability of seedling rubber; the best trees com-

pare favourably with those in the buddings (disregarding age and size), but the medium and poor classes are much lower. Curve 5 shows a case of starved deteriorated rubber, where the yield happens to be at its best owing to an advantageous low cut. Curve 6 is for a stand of similar age showing more rapid deterioration among the poorer class of trees only (probably due to poor drainage). All the yields shown are for a period of good yields: the annual crop would be equivalent to about eight times the monthly figure given.

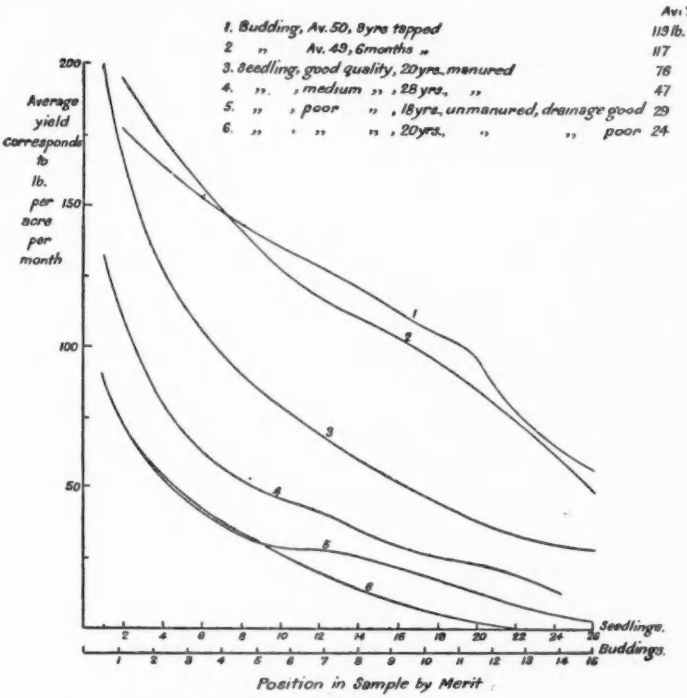
Av. Yield.
1. Budding, Av. 50, 8 yrs tapped 119 lb. acre/month
2 " Av. 49, 6 months " 117
3. Seedling, good quality, 20 yrs. manured 76
4. " " medium " 28 yrs. " 47
5. " " poor " 18 yrs. unmanured, drainage good 29
6. " " " 20 yrs. " " poor 24
Average yield corresponds to lb. per acre per month
200
150
100
50
1
2
3
4
5
6
2 4 6 8 10 12 14 16 18 20 22 24 26 Seedlings.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Buddings.
Position in Sample by Merit

FIG. 1. Average yield-distribution among members of a sample of trees.

As a further illustration, Fig. 2 shows the similarity of standard produced by manuring different kinds of rubber. Two very different stands (Expts. 1 and 2) are found to give identical curves for the completely manured plots, though one stand, on virgin soil, was 8 years old when manuring began, and the other, on exhausted soil, was 14 years old. The different positions of the control curves show how much farther deterioration has gone in the one case than in the other. The evidence is suggestive of a limit for the standard to which most manured rubber can attain, which would mean that manuring too early or too heavily may be wasteful, and that economical application must be designed to maintain moderate standards of yield only. Arrest of deterioration, rather than

improvement above normal, is the special province of manuring old seedling rubber.

The curves have also been analysed to see how the benefit from manuring is distributed among the different classes of trees. The variation is so large, and the factors so many (age, soil, tapping history), that a further accumulation of data will be required before clear conclusions can be reached. But the preliminary survey opens up interesting possi-

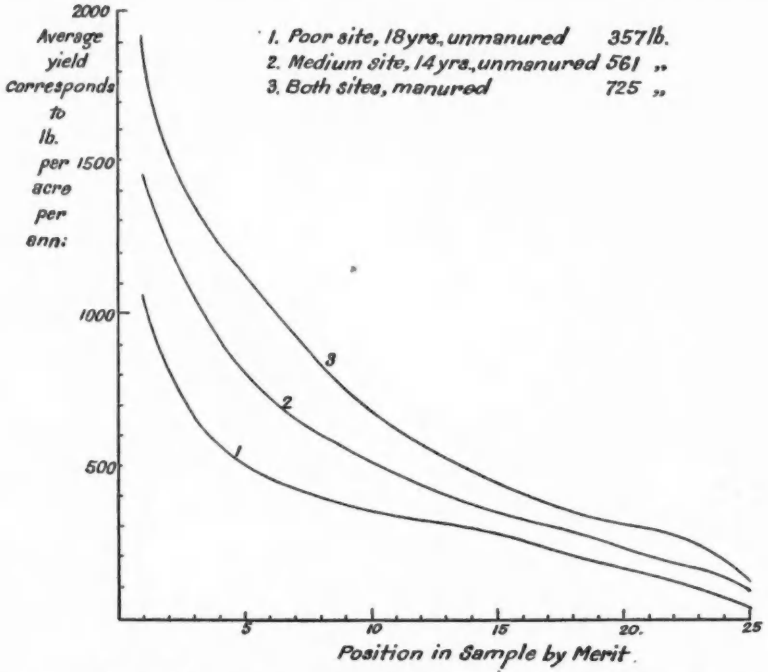

FIG. 2. Yield-distribution illustrating conformity to same standard when manured.

bilities, which well illustrate the greatly extended information made available by the new method of recording. In certain cases, mainly the older stands, the best trees contribute to the manurial response out of all proportion to the others, thus raising the question of the feasibility of selective manuring. At the other extreme, consideration of the poor response from the worst class of trees, supposing each tree to remain permanently in its class, enables one to pronounce upon the desirability or otherwise of thinning them out before undertaking any expensive programme of manuring.

Revised results.—The new results to be recounted refer to the eleven 25-plot experiments described in the previous paper [1, p. 311], where the results extended to the end of 1935, the fifth year of action of the manures. The present account covers yields taken between May and

October, 1937, the seventh year of manuring. The changes shown are therefore a combination of the advance in field-responses and of such corrections as the improved technique of recording has introduced. Table 1 summarizes the new data, two or more rounds of measurement being incorporated in each of the entries. The period covered by each test is only ten days, so that such seasonal influences as may have affected the responses will be reflected in the figures, to be resolved by later results. It should be stated that part of the period of the tests has been marked by unusually dry weather. The data cannot be regarded as definitive, but they are of sufficient volume and consistency to establish a new interpretation, and because of this revision of previously announced conclusions it was thought to be important not to delay publication.

The new figures show in every case significant increases due to manuring. The average increase from sulphate of ammonia (B plots) is 37·7 per cent., which corresponds very well indeed with the figure given by larger scale trials of the same period of treatment. The average effect of the complete inorganic fertilizer (E), 52·7 per cent.,[1] is significantly greater than that for any other treatment. The superiority of E over B is distinctly established in six cases out of eleven, and denied by a significant amount in one case only (No. 9). One must therefore revise the conclusion expressed in the previous paper that B and E were for practical purposes nearly equal, even though these experiments form only part of the evidence there cited. Owing to the uncertainties now attaching to some of the past records, it must be supposed that this difference has been gradually developed and is not a special feature of the particular stage now reached. In one case only, No. 1, the response to sulphate of ammonia fails unless backed by minerals; in this experiment manuring began at the same time as tapping, long before prospects of deterioration made treatment necessary. A benefit from K added to N approaches a significant level in one or two cases, but in the average this is cancelled by two depressive cases (Nos. 9 and 10), though there are no apparent soil differences to account for it. The potash effect in No. 2 was brought out at the onset of a rainy season, and time will be required for its elucidation.

The following notes on the individual cases will assist interpretation.

No. 1. Young rubber, manured since tapping, high cut disadvantageous for yield. ABC tapping last two years, yields on control still high. Nitrogen without minerals not effective, 'complete inorganic' the best. Not yet economic.

No. 2. Normal cut, undulating laterite soil. Moderate yield only. Prominence of NK due to one round which showed flush yields after rains. 'Organic' plots very low response.

No. 3. Normal cut, high stand of well-developed trees on typical granite soil. Manuring began before deterioration was in sight. Highest yield of all experiments. N is nearly as good as NPK, and is the only economic treatment.

No. 4. Land poorly drained. Both complete fertilizers are significantly better than N.

No. 5. White clay, poor drainage. Typical case with normal cut and economic returns. All treatments significant, 'complete inorganic' the best, but simple N the most profitable.

[1] A similar comparison of growth since manuring began shows B plots 55·3 per cent. and E plots 64·5 per cent. over control.

No. 6. Returns not quite economic owing to high cut affecting yield-level. 'Complete inorganic' gives double the increase that simple N gives. The depression due to K (comparing NK with N) approaches the conventional 5 per cent. level of significance.

No. 7. Undulating lateritic soil. Typical normal cut in old rubber with economic returns. All treatments significant, with NPK the best and the most economic, giving double the increase of N. Suggested benefit from K, though soil is similar to No. 6.

No. 8. One-third cut in high position. 'Organic' plots low response, N by itself is the only economic treatment.

No. 9. Eroded hills of heavy quartzitic soil. High cut with many dry trees on control plots. Economic returns. High potash is apparently depressive, since both NK and NPK are significantly below N and 'organic'. N is the best treatment. Unusual case of high response to 'organic'.

No. 10. Orchard type on poor exhausted site. High cut on hard virgin bark, half trees in control areas being dry in this position. K is significantly depressive unless P is also present. NPK significantly better than N or NK.

No. 11. Similar rubber to No. 10. Normal cut 20 in. from ground, giving high returns. Taking NK and NPK together the mineral addition is significantly an improvement.

It should be clearly understood that, although the structural improvements in the tree produced by manuring proceed smoothly and are absolute, the advantage reaped as extra crop is related to the tapping system and in commercial practice would partly depend on the views taken when tapping policy was determined. In each experiment the tapping of all plots has been kept uniform, with simultaneous change-over, and the system pursued has been that suitable to the unmanured controls, as far as that could be done without resting. That is to say, a conservative view of bark-reserves and rate of renewal has guided policy. The bark-reserves are now, after seven years' treatment, so entirely improved on the manured plots that no fears for the future need be felt, and a shorter renewal-period would seem to be fitting. The experimental increases shown are therefore not so large in these later years as would have been obtained on commercially treated areas, where tapping would have been put on a less conservative basis after the first stages of recovery had been secured, in the knowledge that continued manuring would ensure future bark-renewal. For this reason certain experiments (such as No. 11), where the tapping-cut is in a good position, can be considered as more typical than others, and a distinction has been drawn between these and those where crop is being sacrificed by carrying the cut to high positions at the change-over, in order to provide a longer renewal-period for the sake of the unmanured plots. In Nos. 9 and 10, for example, the cut is on starved and hardened virgin bark above the panel last used, and in this position about half the trees on unmanured plots are dry. Manured plots are much better in that respect, but it is known that even these give little more than half the crop that could be derived from a normal lower cut on the renewed bark, and such a position of cut would be merited by the general bark conditions.

Poaching is much in evidence in these old experiments. Boundary

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TABLE I. *Yields from Eleven Experiments of Same Design*

(Grams of rubber per tree per tapping in 7th year of annual applications)

No.	Age Yrs.	A Control	B N only (4 cwt. S/Amm. per acre)	C NK	D Mixture with 'organics'	E NPK (Nitrophoska 16·5 : 16·5 : 21·5)	Standard error	Mean of manured plots: lb./acre/annum	Girth Control in.	Girth trend-indices	
										Control	Manured
1*	14	15·17	15·88	17·29	18·03	19·34	0·540	622	33·2	0·406	0·685
2	26	17·38	20·94†	23·40†	18·69	21·69	0·454	463	39·8	0·411	0·590
3	20	19·76	23·22†	23·41	22·49	24·39	0·840	825	34·6	0·207	0·480
4	23	13·21	15·94†	16·65	17·16	18·41	0·371	493	38·6	0·405	0·567
5	18	10·23	15·18†	14·86†	14·81	17·47†	0·471	429	33·7	0·428	0·570
6*	17	9·43	11·54	10·03	11·18	14·36	0·603	436	29·8	0·467	0·627
7	28	11·76	14·77†	16·17†	16·28	19·68†	0·680	419	39·2	0·265	0·495
8*	23	10·18	14·17†	13·82	11·52	14·43	0·501	409	35·4	0·429	0·576
9*	17	4·36	13·53†	10·58†	13·41†	11·48†	0·539	367	27·9	0·292	0·585
10*	20	3·06	9·40†	7·85†	9·63	10·92†	0·402	333	26·4	0·205	0·465
11	18	10·98	18·21†	19·68†	16·68	19·51†	0·554	653	22·6	0·262	0·750
Average		11·41	15·71	15·79	15·44	17·43	0·167	..	..	0·343	0·581
Comparison, %		100·0	137·7	138·4	135·3	152·7	..	..	..	..	..
Extra crop		..	4·30	4·38	4·03	6·02	..	..	..	..	..
Equivalent running cost of fertilizers, rubber valued 20 cents		..	2·33	3·70	7·70‡	5·80	..	..	..	..	..

Each experiment consisted of five randomized blocks of five treatments, and approximately 200 trees per plot.

A, D half-spiral tapping: except No. 8 on ⅓rd cut, and No. 1 ABC tapping since 1936.

Each plot was subject to at least two rounds with an interval between, in which 1 tree in 7 was sampled on one tapping day.

* These trees have abnormal cut on virgin bark above the previous panel, which gives low yields and, in the worst cases, a very high proportion of dry trees.

† Plots at present showing economic return.

‡ This is the present cost of a mixture giving N equivalent to that on other plots, but in the past these plots received for several years pure 'organics' giving about ⅓rds the amount of N, at greater cost.

rows have been excluded from the sampling, so leaving three tree-rows between test areas, but an estimate made in Expt. No. 1, based upon measurements of contiguous rubber in the same block as the experiment for a check control, showed that 7 per cent. might be added to the apparent percentage benefits to allow for the improvements which the control plots have managed to make by poaching on their neighbours.

The two systems of recording were allowed to overlap in time so as to secure a comparison between them. In some experiments the agreement in all details was very good, as should be, and in all experiments the figure for total monthly crop (14 tappings) agreed well enough with the estimate of it provided by the sampling (1 tapping spread over 5 days), whilst the general averages of these figures agreed with great exactness. The main differences were in the distribution of yield as allotted among the various manured plots. This would indicate that the main point of weakness in the old method was in collection. We may assume that in the past there was a tendency to represent the yields from all manured plots as more uniform than the facts warranted.

Economics of treatment.—Calculations of the economics of treatment based upon these experiments are of limited value, not only because the full possibilities have not been exploited by adapting the tapping-system to improvements seen in the bark, but also because the rate of manuring has been heavier than in most commercial work. Nevertheless, the broad comparisons must be of some interest. Basing calculations upon a value of 20 cents per lb. for the extra rubber produced from a treatment, and upon the present annual rates of outlay and return, it is found that the average of all experiments indicates a very wide margin of profit from the treatment with sulphate of ammonia (70–80 per cent.). The 'complete inorganic' and the NK treatments give a small margin only, whilst the organic mixture is too costly for any profit.

Sulphate of ammonia is thus clearly the safest general recommendation, based on the treatments tested, and the development of practical improvements on this treatment by the use of complete mixtures must depend upon the very promising possibilities of reducing costly elements and rates of application without proportionately reducing the crop benefits. The outstanding problem that remains is to decide on the relative contributions made by P and K to the superiority of NPK over N. On the average NK adds no effect to N, so that the difference might be considered as mainly due to the sum of the P effect and the P by K interaction (all in the presence of N). Unfortunately, the design of these experiments provides no means of distinguishing between these two components, for the logical NP treatment was sacrificed in order to substitute the test of 'organics'. The same question, when examined from exhaustive growth-data of young budded rubber on the same range of soils, showed that P had a large effect while K had none, and the P by K interaction was negligible, but those results may bear little analogy to the question of restoration of yields in old seedling rubber. A cheapening of costs should certainly begin with a reduction in K, for its ratio in Nitrophoska is high (16·5 : 16·5 : 21·5). Phosphate may be reckoned in the cheaper raw (ground rock) form which has proved its effectiveness for

growth of young rubber. Thus straightforward mixtures giving high N, medium P, and low K can be devised that cost about half as much again as the simple nitrogen treatment; and they could be used with or without alternate applications of nitrogen alone, as judgement may dictate. Since the trees are built up slowly and in stages, of which leaf-restoration is usually the first, nitrogen can be given as the chief requirement with the least risk of extravagance, and the best times and amounts of mineral additions leave much room for conjecture, though their ultimate value seems clearly established.

Growth records.—Progress has also been made in the interpretation of the effects of the manures on growth. The previous paper suggested a girth-increment rate of 0·5 in. per annum as a standard below which need of manuring would be much in evidence. It would now appear that a good response has been shown in experiments where the controls have not fallen so low, and the suggested standard might be raised to 0·75 in. per annum.

An improved standard based upon approximate trends is now suggested. As a rough trend-index one may take the ratio of increment in the last year to the average rate of growth since planting (girth divided by age). Rate of growth since tapping would form an improved basis if the necessary data were available. A presumption that the natural law of growth is a uniform rate can be made until a reliable normal curve of growth against age can be provided. The index may fluctuate to the extent that weather causes better growth in some years than in others. But the figures shown in the table, based upon graphical estimates from the last two or three years' growth-measurements, give great promise that the index will prove useful. The unmanured and manured plots fall into two distinct classes, unmanured values being below 0·46 and manured values above this figure. This suggests a rough rule, to be used in conjunction with other field observations, viz. that starved conditions may be presumed if the growth-rate has fallen much below half the average rate since planting.

The average growth-rate on manured plots since the experiments started has been 1·01 in. per annum, and this seems to be a fair standard to associate with adequate bark-renewal. The average for 'unmanured' during the same period is 0·58 in. per annum, which includes, of course, some experiments hardly in need of manuring. Measurements of growth and of bark-thickness serve to indicate the gross improvements produced by manuring, but they are not sufficiently closely correlated with yield for serving to distinguish between cases of restored rubber, that is, for comparing the relative powers of different fertilizers to increase production.

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CEREAL GRAINS AS A SOURCE OF NUTRITIONALLY USEFUL PHOSPHORUS

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THE researches of E. and M. Mellanby [1, 2] on the rickets-producing tendencies of certain cereal diets have led to much work being undertaken to explain the nature of the 'anti-calcifying' factor reported by these workers. The total-phosphate content of grains is high, compared with that of most foodstuffs, and the possibility that the rickets could be due to lack of phosphorus was not considered likely. Investigations during recent years suggest, however, that the tendency for rations in which cereals predominate to induce the formation of faulty bones and teeth is, indeed, due to lack of available phosphorus. Bruce and Callow [3] discuss the literature of the subject, and in their summary state, 'In diets of high calcium-content the apparent rachitogenic effect of cereals, when compared with other material of the same phosphorus-content, is due to the fact that the cereal phosphorus is in an unavailable form.' Much of the phosphorus in cereal grains (and most seeds, apparently) is present as inositol hexaphosphoric acid or phytin phosphorus. McCance and Widdowson [4], working with human beings, showed that 36–63 per cent. of the phytin ingested by adults was excreted unchanged. Lowe and Steenbock [5], working with rats, found that when phytin was the main source of dietary phosphorus, over 50 per cent. of the phosphorus excreted in the faeces was of an organic form. Phytin is not necessarily absorbed to the extent that these figures appear to indicate, however, as phytin not present, as such, in the faeces may merely have been partially broken down by intestinal organisms, but such breakdown products are not necessarily assimilable [4].

Not only is phytin of doubtful value as a source of phosphorus, but it is also possible that a ration containing much phytin may impede assimilation of calcium. Bruce and Callow [3] draw attention to the fact that inositol hexaphosphoric acid may precipitate calcium more effectively than does phosphoric acid. As foodstuffs rich in phytin generally contain but little calcium, this possibility must not be overlooked.

Lowe and Steenbock draw attention to another point of potential practical importance. They show that whereas a substantial fraction of the phytin in a cereal ration may be hydrolysed by rats, such hydrolysis is greatly reduced by the addition to the diet of 3 per cent. $CaCO_3$ or $MgCO_3$. As it is a common practice to add ground limestone to cereal rations, this finding is of considerable significance. Dunlop [6] reports that in certain pig-feeding experiments, animals receiving 4 per cent. $CaCO_3$ as a supplement to a calcium-deficient ration (consisting of 95 per cent. cereals) did not thrive as well as groups on a similar ration containing only 2 per cent. $CaCO_3$.

Work on the nutritional value of the phosphorus present in cereal

grains is of particular interest to Australians. It has been shown [7, 8] that Australian wheats are characteristically low in total phosphorus. From Table 1 it will be seen that Western Australian wheats and oats contain only about half the total phosphorus present in typical British grains. This low phosphorus-content makes it all the more necessary to understand the nutritional significance of the phosphorus present. The following data refer particularly to Western Australia, but certain points seem of general interest.

TABLE 1. *The Phosphorus-content of Western Australian Cereal Grains (as percentage of dry weight)*

	Number of years averaged	*Average total P*	*Range*
'Fair average quality' (F.A.Q.) wheat . .	6	0·24	0·22–0·27
Wheat grown at Merredin (variety Nabawa) .	4	0·26	0·24–0·28
,, ,, Wongon Hills (variety Nabawa)	4	0·22	0·19–0·24
Standard British wheat [9]	..	0·47	..
Oats grown at Merredin	4	0·23	0·21–0·25
,, ,, Wongon Hills . . .	4	0·20	0·17–0·23
Standard British oats [9]	..	0·39	..

Experimental

Grain samples of British and Western Australian origin were analysed for total and phytin phosphorus. The former was estimated by the Richards-Godden modification of the Pemberton-Neumann method, and the latter by a method substantially the same as that described by McCance and Widdowson [4]. It was found that the use of perchloric acid in the digestion of the sodium phytate was unnecessary and inadvisable, as, if the smallest trace of perchloric acid remained after digestion, colour formation was prevented when the phosphorus was estimated by the colorimetric method of Fiske and Subbarrow. Two millilitres of concentrated sulphuric acid suffice to facilitate the digestion. The results are recorded in Table 2.

From Table 2 it appears that even British wheats of good quality cannot be expected to supply much more than 0·12 per cent. of non-phytin phosphorus, and for reasons already discussed, the usefulness of phytin phosphorus is definitely suspect. No work appears to have been done on the ability of ruminants to make use of the various organic phosphates, but it certainly seems unsafe to assume (as do most practical stockmen) that cereal diets always supply ample useful phosphate.

The Australian figures warrant particular emphasis, especially with regard to the feeding of pigs and poultry. Dunlop [6], in his comprehensive pig-feeding trials, showed that for optimum growth about 0·53 per cent. phosphorus was required in the ration of pigs fed on a diet consisting mainly of cereals. A comparable ration made up of Western Australian grains and containing 5 per cent. meat-meal would supply only about 0·28 per cent. total phosphorus and about 0·14 per cent. non-phytin phosphorus. Most farmers are aware that cereal rations need

supplementing with calcium, and it appears that there is also need to guard against possible phosphorus deficiency. Even in Britain, under certain conditions liable to retard the assimilation of phytin phosphorus, lack of useful phosphorus may be an unsuspected factor limiting the growth rate. If, as is suggested by the work of Lowe and Steenbock [5], the use of $CaCO_3$ reduces the absorption of organic phosphorus, then the use of 4 per cent. or more of ground limestone in the ration may lead

TABLE 2. *Total Phosphorus and Phytin Phosphorus present in Cereal Grains (as percentage of the dry weight)*

	Total P	*Phytin P*	*Phytin P as % of of total P*	*Non-phytin P*
WHEAT				
Western Australia				
Standard blend (F.A.Q.), 1935	0·27	0·17	63	0·10
Nungarin (Totagin) . .	0·26	0·17	65	0·09
Merredin (Nabawa) . .	0·27	0·19	70	0·08
Wongon Hills (Nabawa) .	0·19	0·12	63	0·07
Chapman (Nabawa) . .	0·31	0·24	77	0·07
English				
York (Crown) . . .	0·42	0·31	74	0·11
York (Sq. Master) . .	0·44	0·32	73	0·12
OAT GRAIN				
Western Australia				
Merredin (Mulga) . .	0·25	0·14	56	0·11
Wongon Hills (Mulga) . .	0·19	0·13	69	0·06
Chapman (Mulga) . .	0·22	0·14	64	0·08
Nungarin (Mulga) . .	0·31	0·18	58	0·13
British				
Scotch (Victory) . . .	0·41	0·28	68	0·13
York (Victory) . . .	0·44	0·29	66	0·15

to phosphorus deficiency. It certainly appears that farmers should be advised to use bone-meal or a mineral phosphate, in addition to $CaCO_3$, to balance cereal rations when no skim milk is available.

Leguminous seeds.—To obtain information concerning the value of leguminous seeds as a source of useful phosphorus, several samples grown in Western Australia have been analysed. The results are recorded in Table 3.

When compared with standard analyses from other countries [9] the total-phosphorus content of field peas grown in Western Australia appears quite normal, and they contain double the amount present in local cereals. The non-phytin phosphorus present in field pea B is equal to the total phosphorus found in the average of F.A.Q. wheats. It is interesting to note that one of the samples of lupin seeds contained only a trace of phytin phosphorus, but this sample appears abnormal, containing only 0·26 per cent. total phosphorus, whereas of nine other samples

analysed the lowest value found was 0·33 per cent. and the average was 0·41 per cent. total phosphorus. The figures for the two Subiaco samples (grown on poor, unfertilized, sandy soil) seem typical, and indicate that lupin seeds, so valued as sheep feed, may be good sources of available phosphorus.

TABLE 3. *Total Phosphorus and Phytin Phosphorus present in Leguminous Seeds of Western Australian Origin (as percentage of dry weight)*

	Total P	*Phytin P*	*Phytin P as % of of total P*	*Non-phytin P*
Field Peas (White Brunswick)				
A. Tipperary, 1935	0·38	0·22	58	0·16
B. Burekup, 1935	0·47	0·24	51	0·23
Average of 5 other samples	0·42	..	..	..
Tangier Peas (*Lathyrus tingitanus*)				
Dwarda, 1933	0·32	0·15	47	0·17
„ 1934	0·33	0·13	40	0·20
„ 1935	0·35	0·14	40	0·21
Wonnerup, 1935	0·33	0·14	42	0·19
Blue Lupins (*Lupinus pilosus*)				
Wongon Hills, 1935	0·26	trace only	..	0·26
Subiaco, 1935	0·33	0·10	30	0·23
„ 1936	0·39	0·13	33	0·26
Average of 7 other samples	0·42	..	..	..

The data in Table 3 can be used to furnish a further argument for the extended use of leguminous seeds by farmers in Australia for feeding live stock.

Summary

1. Samples of cereal grains of British and Australian origin have been analysed to determine the contents of total phosphorus and phytin phosphorus.

2. It was found that British grains of normal phosphorus-content (0·41–0·44 per cent.) contained 0·28–0·32 per cent. phosphorus as phytin phosphorus. Grains of Western Australian origin (total phosphorus = 0·19–0·31 per cent.) contained 0·12–0·24 per cent. phytin phosphorus.

3. The practical significance of these figures is discussed in the light of published work dealing with the subject.

4. Samples of Australian leguminous seeds were also analysed for total phosphorus and for phytin phosphorus. It seems that leguminous seeds supply more non-phytin phosphorus (0·17–0·26 per cent.) than do cereal grains (0·06–0·13 per cent.).

This investigation was carried out in the Biochemical Department of the Rowett Research Institute, Aberdeen, during the tenure of a Hackett Studentship granted by the University of Western Australia.

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THE RELATION BETWEEN BODY-CONFORMATION AND PRODUCTIVITY IN THE CYPRUS FAT-TAILED SHEEP

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THE main object of this investigation was to find out whether it is possible to get some indication of the productive capacity of an animal by judging its body-conformation. The importance of this problem in animal husbandry is generally accepted and the results of many investigations have already been published. Thus Kronacher-Ogrizek [1] and Döhrman [2] have found a distinct relationship between the body-conformation and the capacity for work of horses and oxen, and the development of those parts of the body which are essential to the performance of work has increased the working efficiency of the animal. The writer has also published a thesis on the working oxen of the Illyric breed in Jugoslavia [3]. With milking animals, however, and especially dairy cattle, it has not been possible, with few exceptions [4], to find any important relationship between the development of particular body-measurements and the production of milk, and such indirect connexions as there are cannot be accurately gauged. Despite this fact it appeared to be worth while to undertake an investigation on these lines with milking sheep, for the following main reasons:

1. A large number of animals was available, all of which could be fed and managed in the same way during the whole period of the investigation.
2. These sheep had to obtain their normal food on the poorest natural pasture, and therefore it seemed likely that those animals which had a body-conformation enabling them to collect a larger quantity of food while grazing would produce the most milk. Thus it was thought, in the first place, that any relationship which might exist would be best demonstrated by the height at withers, by the chest measurements, and by the skeleton of the animal.

The intention was to use a system of control of the productive capacity of the animals by which the individual milk yields could be ascertained as accurately as possible, and to record the results in terms of some standard method.

Material and methods.—The material used for the investigation consisted mainly of the flock belonging to the Cyprus Farming Co., at Kouklia in the Messaoria plain of Cyprus. During the season 1935–6 the flock contained 600 ewes and 220 yearlings, which were purchased from different parts of the Island. All animals were marked with small numbered clips in the ears and all measurements, &c., were recorded in a loose-leaf 'flock-book', a specimen sheet of which is given in the Appendix.

The body-measurements were taken with a Lydtin rule, a compass, and a tape, and were expressed as percentages of the height at withers.

Every 15 days the milk obtained from each ewe was weighed, the first

and last day of milking being noted, and the amount of milk for each period of 15 days was calculated by multiplying the average of the two figures obtained by the number of days. In addition to this actual 'milk yield' the 'standard milk yield', based on a suckling-period of 30 days, was calculated for each ewe.

The weight of all lambs was taken at birth, and that of ram-lambs also at the date of selling and that of ewe-lambs at weaning. The weight at selling or at weaning, less the birth-weight, divided by the number of days suckling, gave the average daily live-weight increase during the suckling-period.

Before shearing, the length of the wool was measured on the shoulder of the animal; after shearing, the fleece-weight and the live-weight of the animal were recorded.

Body-Conformation

Outward appearance.—The hair of the head and legs on most of the sheep is coloured, many different markings being found. The markings on the face, eyes, and lips are nearly always fawn. The colour of the head, usually white, may be fawn, brown to black-brown, or grey to black-grey. The legs are usually spotted, and the pasterns are variously coloured and seldom without marks.

The wool is usually white. Approximately 2–3 per cent. of the animals have larger or smaller markings on their body, mostly brown to black-brown, seldom grey. Even those animals whose fleece is almost entirely brown have also some white spots, usually at the end of the fat-tail.

Horns are, as a rule, found on the rams, although hornless rams are not infrequent. Ewes are mostly hornless, only about 2–3 per cent. having horns or rudimentary horns.

The shape and size of the ears vary considerably. Animals with only rudimentary ears are sometimes found (about 1 per cent.). Most of them have large drooping ears, but about 10 per cent. of them have ears thick, fleshy, and small.

The fat-tail of the Cyprus sheep is very well developed, and one can usually judge the state of nutrition of the animal from the appearance of the fat-cushion. The tail is widest at the junction of the upper and middle thirds, and then tapers gradually. It makes half a turn (either to right or to left) at the junction of the middle and lower thirds, i.e. much higher than in the Awasi and other sheep of the neighbouring countries, in which the end of the tail is somewhat button-shaped. On well-fed animals, and especially on rams, the fat-tail reaches close to the ground. The posterior surface is covered with wool, but the anterior or inner surface is naked.

Body-measurements.—Table 1 gives the means, standard-errors, and deviations of the absolute body-measurements of 657 adult ewes. Table 2 gives the relative body-measurements expressed as percentages of the height at withers. The variation of each measurement in the majority of ewes is given in columns 5 and 6 of both tables.

The height at withers (H. at W.) averaged 66·71 cm., the minimum

being 60 and the maximum 75 cm. In 80 per cent. of the ewes measured, the H. at W. fluctuated between 64 and 70 cm.; 12·7 per cent. were below 64 cm. and 7·3 per cent. were above 70 cm.

TABLE 1. *Means, Standard Errors, and Deviations of the Absolute Body-measurements (cm.)*

(*n* : 657)

	1	2	3	4		5	6
						% of ewes within limits given in column 6	*Variation in cm. of majority of ewes*
	M.	*S.E.*	*Dev.*	*Min.*	*Max.*		
Height at withers	66·71	0·11	2·80	60	75	80·0	64–70
,, back	67·10	0·11	2·74	58	75	81·5	64–70
,, crupper	66·90	0·11	2·76	59	75	81·7	64–70
Length of body	66·41	0·14	3·55	56	81	68·5	64–70
Depth of chest	30·85	0·06	1·62	26·5	37	80·2	29–33
Breadth of chest	20·19	0·07	1·90	13·5	26·5	77·0	18–22
,, pelvis	22·58	0·08	2·04	18	29·5	69·5	21–25
Chest, circumference	86·30	0·20	5·06	72·5	100·0	56·0	84–90
Shin-bone, ,,	7·54	0·02	0·43	6	9	98·0	7–8
Length of head	19·89	0·04	1·03	17·5	24	80·0	19–21
Breadth of head	11·96	0·02	0·46	10	13	91·0	11·5–12·5

TABLE 2. *Means, Standard Errors, and Deviations of the Relative Body-measurements*

(*n* : 657)

	1	2	3	4		5	6
	In % of height at withers					*% of ewes within limits given in column 6*	*Variation in % of H. at W. of most ewes*
	M.	*S.E.*	*Dev.*	*Min.*	*Max.*		
Height at withers.	100·00	..	..	..	..	..	..
,, back	100·67	0·09	2·21	94	110	74·7	98–102
,, crupper	100·39	0·12	3·06	90	112	61·8	98–102
Length of body	99·77	0·19	4·97	86	113	80·5	94–106
Depth of chest	46·25	0·10	2·46	39	58	72·7	44–48
Breadth of chest	30·25	0·11	2·80	20	38	61·6	28–32
,, pelvis	33·92	0·13	3·25	26	44	70·0	31–37
Chest, circumference	129·97	0·28	7·15	110	152	68·0	124–136
Shin-bone, ,,	11·33	0·02	0·60	9·5	13	91·0	10·5–12
Length of head	29·85	0·07	1·81	22	39	86·0	28–32
Breadth of head	17·90	0·03	0·78	15·5	20·5	88·7	17–19

The course of the back-line is straight in the majority of animals. Concave or convex backs are few. Animals with a rising back-line occur more often than those with a sloping back-line.

The body has an average length of 66·41 cm. and is therefore nearly as great as the height at withers (99·77 per cent. of H. at W.).

The depth of chest averaged 30·85 cm., with a minimum of 26·5 cm. and a maximum of 37 cm. In 80·2 per cent. of the animals it fluctuated from 29 to 33 cm., in 11·6 per cent. it was below 29, and in 8·2 per cent. above 33 cm. It can therefore be concluded from the figures given in the tables that the chest measurements of Cyprus sheep are very well developed.

Comparison with sheep of neighbouring countries.—The data given in Table 3 provide a comparison of the measurements of the Cyprus

fat-tailed sheep with those of the Palestine Awasi and the Anatolian Karaman sheep. It is seen that the back-line of the Cyprus fat-tailed sheep is more uniform than that of either of the other breeds. The Awasi sheep have on the average a greater, and the Karaman sheep a lower, height at withers. The length of body in proportion to the height at withers is also greatest in the Cyprus breed, the Awasi being next; the Anatolian Karaman sheep are rather short in body. The chest measurements in proportion to the height at withers are also better developed in the Cyprus breed.

TABLE 3. *Comparison of Body-conformation of the Fat-tailed Sheep from Cyprus, Palestine, and Anatolia*

	Cyprus Fat-tailed Sheep (*n*: 657)		*Palestine* [5] *Awasi Sheep* (*n*: 180)		*Anatolia* [6] *Karaman Sheep* (*n*: 87)	
	cm.	*As % of H. at W.*	*cm.*	*As % of H.W.*	*cm.*	*As % of H. at W.*
Height at withers	66·71	100·00	68·00	100·00	63·55	100·00
,, back	67·10	100·67	67·00	98·50	62·37	98·14
,, crupper	66·90	100·39	67·50	99·30	62·97	99·09
Length of body	66·41	99·77	67·00	98·50	59·45	93·47
Depth of chest	30·85	46·25	27·00	39·70	28·83	46·05
Breadth of chest	20·19	30·25	18·00	26·40	16·76	26·39
Chest, circumference	86·30	129·97	80·00	117·60	..	..
Shin-bone, circumference	7·54	11·33	..	..	7·20	11·33
Breadth of pelvis	22·58	33·92	..	..	18·01	28·52
Length of head	19·89	29·85	..	..	23·02	36·70
Breadth of head	11·96	17·90	..	..	10·98	17·98

Productivity

Production of milk.—Of the 456 ewes that were milked regularly, it was only possible to include the results of 414, the other 42 having to be eliminated owing to various causes that affected the reliability of the figures. As the ram-lambs for sale could not all be weaned exactly at the same age, it was necessary to standardize the figures for milk yield in order to be able to compare the results, and to use them as a basis for future selection. In Cyprus it is usual to sell a number of lambs at 3 to 4 weeks old, as they then fetch good prices for slaughter and the ewes can be milked for a longer time. In view of these facts it seemed best to establish a standard based on a suckling-period of 30 days, for lambs, this being the shortest possible period to allow.

Since the majority of ewe-lambs were reared on their dams they had to be allowed a minimum period of 60 days' suckling, and the milk yield of their dams was consequently not recorded until they reached a later stage of lactation than the ewes whose lambs were sold earlier. In order, therefore, to ascertain the yield of milk they would have given if milked after suckling a lamb for only 30 days, it was necessary to obtain the average yield of milk for this interval for a number of ewes. There were in the flock 109 ewes whose lambs were sold when one month old. From

these ewes it was possible to obtain milk records from the thirty-first day after lambing until the end of lactation.

Beginning with the thirty-first day of lactation, the quantity of milk from these ewes was calculated separately for each subsequent interval of 15 days. At the end of lactation the total amount was found and the quantity for each interval was expressed as a percentage of the total amount.

In Table 4 the percentage figures are given with their means, standard errors, and deviations, as well as the range of variation for the majority of the ewes. By means of these average figures the 'standard' milk yield was calculated for the remaining 292 ewes. The formulae used were:

$SY = A + x$ and $x = Af$, where SY is the standard milk yield, A is the amount actually milked, x is the assumed amount of milk for the missing intervals, and f is the constant factor for the missing intervals in question, as given in column 7 of Table 4, whereby $f/1$ is for the period from the 31st to the 45th day $\left(\frac{16{\cdot}36}{100-16{\cdot}36}\right)$, $f/2$ from 31st to 60th day $\left(\frac{30{\cdot}44}{100-30{\cdot}44}\right)$, and so on.

TABLE 4. *Course of Lactation*

1 *Intervals during the lactation period*	2 *% of total milk yield obtained*	3 *S.E.*	4 *Dev.*	5 *% of ewes within limits given in column 6*	6 *Variation in % of majority of ewes*	7 *Factor for calculating standard milk yield (f)*
Days						
1– 30	Suckling period					
31– 45	16·36	0·34	3·51	66	13–19	0·196
46– 60	14·08	0·24	2·56	78	12–16	0·439
61– 75	12·21	0·17	1·82	83	10–14	0·744
76– 90	11·61	0·15	1·54	90	10–14	1·186
91–105	10·58	0·13	1·34	87	9–12	1·844
106–120	9·32	0·12	1·28	82	8–10	2·870
121–135	7·94	0·13	1·35	93	6–10	4·587
136–150	6·49	0·14	1·46	90	5– 8	7·764
151–165	5·11	0·19	1·87	80	4– 7	14·873
166–180	4·43	0·17	1·62	82	3– 6	..
181–dry	1·87	..	..	..	..	..
	100·00					

In practice lambs seldom suckled for more than 90 days, and if this was exceeded, as for instance when rearing ram-lambs for breeding, the ewe's surplus milk was usually of no importance; the factors $f/5$, $f/6$, $f/7$, $f/8$, and $f/9$ will therefore, as a rule, not be used at all.

The production of milk from 414 ewes averaged 67·5 kg., excluding the 30 days' suckling-period. Yields varied from 10 kg. up to 160 kg., which clearly shows the need of careful selection, since the cost of keeping each ewe is approximately equal. The milk yield fluctuated between

42 and 86 kg. for 64 per cent. of the recorded ewes; for 15·5 per cent. it was below, and for 20·5 per cent. it was above this range.

The lactation period, counted from the day of lambing to the last day of milking, lasted for an average of 180 days. Again there was a wide variation, some ewes having a lactation-period of 100 days and others up to 240 days. In 77 per cent. of the ewes the length of lactation was between 155 and 205 days, for 16·7 per cent. it was below and for 6·3 per cent. it was above these figures. In the last intervals of the lactation the daily yield per animal was small, but the milking was continued in order to ascertain the longest period of lactation.

TABLE 5. *Productivity of Cyprus Fat-tailed Sheep*

	n	*M*	*S.E.*	*Dev.*
Milk yield (kg.)	414	67·50	1·27	25·87
Length of lactation (days)	414	180·25	1·34	27·27
Fleece-weight of ewes (kg.)	311	1·619	0·02	0·353
,, ,, yearlings (kg.)	94	2·048	0·04	0·40
,, ,, rams (kg.)	11	2·758	..	..
Length of wool (at shoulder) of ewes (cm.)	480	22·29	0·17	3·79
,, ,, ,, yearlings (cm.)	95	25·17	0·38	3·74
,, ,, ,, rams (cm.)	11	27·50	..	..

The fat-content of the milk was found to increase gradually towards the end of lactation, some ewes showing 7 per cent. at the beginning and as much as 11·2 per cent. fat at the end of the lactation.

Production of Wool.—The sheep were shorn in April, 1936, with hand-shears, as is usual in Cyprus. The length of the wool, measured on the shoulder of the animal, the fleece-weight, and the live-weight were recorded immediately after shearing (Table 5).

The wool usually covers the whole body except the legs, head, and under-surface of belly, chest, and neck. These parts are covered with hair, but in 42·3 per cent. of the animals examined the front part of the head was covered with wool. In 13·3 per cent. of the animals the front part of the chest was not covered with wool but with hair.

The average length of wool from 480 adult ewes was 22·29 cm., with a minimum of 10 cm. and a maximum of 31 cm.; for 83·7 per cent. of them it varied between 18 and 28 cm., for 11·8 per cent. it was below and for 4·5 per cent. it was above these limits. In 95 yearlings, shorn for the first time at 15–16 months, the average length was 25·17 cm. (min. 13, max. 36 cm.), and the variation in 82 per cent. of them was 22–30 cm. The wool-length in 11 rams averaged 27·5 cm. (min. 19, max. 36 cm.).

The average fleece-weight for 311 adult ewes was 1·619 kg. (min. 0·9, max. 3·4 kg.), and in 82 per cent. of the animals it varied between 1·2 and 2·0 kg. The weight of the first fleece of yearlings averaged 2·05 kg. (min. 1·2, max. 3·6 kg.), for 80 per cent. of them it varied between 1·5 and 2·3 kg., and for 18 per cent., 2·3 kg. For 11 rams the average was above 2·76 kg. (min. 2·0, max. 4·0 kg.).

The wool is of a rather coarse, mixed type, and its quality seems to be similar to the wool of the Anatolian Karaman sheep, examined and de-

scribed by Spöttel [6]. The fleece of animals with short wool (10–14 cm.) is usually more close and appears dull, and it does not show any parting along the back, whereas that of animals with longer wool appears more open and glossy. Only 3·3 per cent. of the examined animals had short wool.

Live-weight.—Table 6 gives the means, standard errors, and deviations for the live-weight. The average birth-weight of 233 ram-lambs was 5·04 kg. (min. 3·1, max. 6·6 kg.). Of these lambs, 66 per cent. varied in birth-weight between 4·5 and 5·5 kg. For 226 ewe-lambs the average was 4·82 kg. (min. 2·5, max. 6·1 kg.); for 69·5 per cent. of them it varied between 4·5 and 5·5 kg. In twin lambs the birth-weight varied from 3·5 to 5·1 kg., with an average of 4·22 kg. for each twin.

TABLE 6. *Live-weight of the Cyprus Fat-tailed Sheep according to Age and Sex, in kg.*

	n	*M*	*S.E.*	*Dev.*
Lambs.				
Birth-weight of ram-lambs	233	5·04	0·04	0·58
„ ewe-lambs	226	4·82	0·04	0·55
Weight increase per day: 25–30 days old	89	0·248	0·004	0·04
„ „ 31–60 „	84	0·225	0·004	0·04
„ „ 61–90 „	170	0·207	0·002	0·04
„ „ average of	362	0·222	0·002	0·04
Slaughter-weight as % of live-weight	45	63·33	0·69	4·62
„ of old lambs up to 50 days	20	66·20	..	..
„ of old lambs up to 51–85 days	25	61·04	..	..
Live-weight of ewe-lambs at weaning, 8–10 weeks	196	17·97	0·13	1·82
Live-weight of ewe-lambs at 6–7 months	255	27·77	0·22	3·47
Yearlings.				
Live-weight of old ewes, at 17–18 months, after shearing in April	90	36·77	0·51	4·82
Adult ewes.				
Live-weight after shearing in April	575	39·52	0·22	5·32
Adult rams.				
Live-weight after shearing in April	11	64·60	..	..

The daily gain in live-weight was calculated by deducting the birth-weight from the weight at the time of selling or weaning, and dividing by the age in days. The lambs were then divided into three classes: 25 to 30, 31 to 60, and 61 to 90 days old; and the means were calculated statistically for each class.

For 89 lambs under 30 days the average increase per day was 0·248 kg. (min. 0·11, max. 0·35 kg.), and 70·7 per cent. varied between 0·220 and 0·280 kg. In the second class the average increase was 0·225 kg., and 57 per cent. varied between 0·200 and 0·240 kg. For the third class the average increase was 0·207 kg. (min. 0·130, max. 0·350 kg.), and 80 per cent. varied between 0·170 and 0·250 kg.

The increase in weight was higher in the first month and decreased

gradually as the lambs grew older. The correlation coefficient between the weight-increase per day and the age of the lamb gave

$$r = -0{\cdot}4005 \pm 0{\cdot}0441.$$

The slaughter-weight of the lambs up to 50 days old averaged 66·2 per cent. of their live-weight (min. 61, max. 75 per cent.). The lambs slaughtered when 51 to 85 days old gave an average of 61 per cent. (min. 53, max. 70 per cent.). The average slaughter-weight of all the 45 lambs examined was 63·33 per cent. of the live-weight.

At weaning, i.e. at the age of 8–10 weeks, the average live-weight for 196 ewe-lambs was 17·97 kg. (min. 14, max. 22 kg.) In 80 per cent. of these lambs the variation was between 16 and 20 kg. At the age of 6–7 months the average live-weight of 255 ewe-lambs was 27·77 kg. (min. 20, max. 26 kg.). In 67 per cent. of these lambs the variation was between 25 and 31 kg. At 17–18 months old the average live-weight of 90 female animals was 36·77 kg. (min. 27, max. 53 kg); variation 33–40 kg. for 71 per cent. The adult ewes were also weighed in April, after shearing, and the average weight of 575 animals was 39·52 kg. (min. 27, max. 59 kg.). In 68 per cent. of these ewes the weight varied between 35 and 45 kg. The adult rams, weighed after shearing, gave an average of 64·60 kg. (min. 51·4, max. 75·8 kg.).

Relation between Body-conformation and Productivity

Milk.—The correlations between body-measurements and milk-production are given in Table 7. For this purpose it was possible to take the measurements of 307 ewes which had a normal lactation. Their standard milk yield was calculated as described above (page 29). The limit of significance adopted was that of twice the standard error [7].

The correlation between the height at withers and milk-production gives a slightly significant coefficient of $r = +0{\cdot}1571 \pm 0{\cdot}0557$, indicating that the taller ewes were better milkers, though this point requires further investigation owing to the smallness of the coefficient.

No other correlation could be found between the body-measurements and the milk-production of ewes.

TABLE 7. *Correlation Coefficients for Body-measurements and Milk Production*

	n	*r*	*S.E.*
Milk yield—height at withers	307	+0·1571	0·0557
,, —depth of chest	307	+0·0188	0·0571
,, — ,, ,, as % of H. at W.	307	−0·1082	0·0564
,, —breadth of chest	307	−0·0743	0·0567
,, —chest-circumference	307	+0·0379	0·0569
,, —length of head	307	+0·0956	0·0565
Milk yield—live-weight	307	−0·0183	0·0574
,, —fleece-weight	172	+0·1176	0·0752
,, —maximum daily yield	307	+0·7464	0·0253
,, —length of lactation	307	+0·6558	0·0324
Maximum daily yield—length of lactation	307	+0·3069	0·0517

Thus no correlation was found either between the milk yield and the live-weight or between the milk yield and the fleece-weight of the ewes.

The maximum daily yield of milk and the length of the lactation-period were also correlated with milk-production in order to express numerically their importance and their mutual relation. This correlation gave a coefficient $r = +0{\cdot}3069 \pm 0{\cdot}0517$, indicating that ewes with a higher maximum daily yield have often also a longer lactation.

Wool.—Coefficients of correlation for wool-production and fleece-weight of the ewes are given in Table 8.

In general, no correlation could be found between the body-measurements and the wool-production of the ewe, the height at withers giving an insignificant coefficient, and both chest-measurements giving correlation coefficients that were only on the border-line of significance.

There was also no significant correlation between live-weight and fleece-weight of the ewe.

TABLE 8. *Correlation Coefficients for Wool-production, Body-measurements, Live-weight, and Wool-length of Ewes*

	n	*r*	*S.E.*
Fleece weight—height at withers . . .	308	−0·0247	0·0569
,, —depth of chest . . .	308	−0·1386	0·0559
,, — ,, ,, as % of H. at W.	308	−0·1233	0·0561
Fleece-weight—live-weight	306	+0·0735	0·0568
,, —length of wool . . .	308	+0·4310	0·0463

Length of the wool, measured at the shoulder of the animal, gave, as would be expected, a positive correlation coefficient with fleece-weight: $r = +0{\cdot}4310$. It can therefore be concluded that in sheep with long coarse wool it is possible to judge the weight of wool by the length of its staple.

Live-weight.—The live-weight of 474 adult ewes was correlated with certain body-measurements, and the results are given in Table 9. The ewes were weighed as nearly as possible at the same date, and as they received similar treatment during the whole period of the experiment it was possible to obtain comparable figures. The correlation coefficients are given in the order of greatest significance. It is seen that the chest-measurements, the height at withers, and the length of body have a very significant correlation to the live-weight of the animal. The length of head and the breadth of pelvis also gave significant, but lower correlations. Expressed as percentages of height at withers, depth of chest gave a slight and length of body no correlation with the live-weight of the animal.

The correlations based on the live-weight of the lambs gave the following results:

No correlation was found between the live-weight of the mother and the birth-weight of its lamb.

The correlation between the birth-weight of the lamb and its weight-increase per day gave the coefficient $r = +0{\cdot}1181$, and was thus only on the border-line of significance.

The age of the lamb gave significant negative coefficients with the weight-increase as well as with the slaughter-weight, thus confirming practical experience.

TABLE 9. *Correlation Coefficients for Live-weight and Body-measurements, &c., of Ewes*

	n	*r*	*S.E.*
Live-weight—chest-circumference	474	+0·4819	0·0353
,, —depth of chest	474	+0·4438	0·0369
,, —height at withers	474	+0·3777	0·0394
,, —breadth of chest	474	+0·3439	0·0405
,, —length of body	474	+0·3433	0·0405
,, —length of head	474	+0·2751	0·0424
,, —breadth of pelvis	474	+0·2276	0·0436
,, —chest-depth as % of H. at W.	474	+0·1536	0·0448
,, —body-length as % of H. at W.	474	+0·0701	0·0457
Live-weight of dam—birth-weight of lamb	419	+0·0935	0·0484
Birth-weight—weight increase per day	362	+0·1181	0·0518
Age of lamb— ,, ,,	362	−0·4005	0·0441
Age of lamb—slaughter-weight	45	−0·5763	0·0996

The Economic Value of Records in Sheep Management

On the basis of the records collected it was possible, at the end of the lambing and milking season, to ascertain the gross receipts from each ewe separately. This was calculated as follows: (*a*) for milk: the total quantity of milk multiplied by the average price of milk per kg.; (*b*) for lambs: the live-weight at selling or weaning multiplied by the average price per kg. obtained; (*c*) for wool: the fleece-weight multiplied by the average price for wool per kg. The net proceeds were obtained by adding the average estimated value of the manure produced and subtracting the average expenses per animal. These figures have provided a useful means of ascertaining in what directions an increase in the profit of a flock can best be attained. The correlation coefficients concerned are given in Table 10.

As Cyprus sheep are kept for producing milk, lambs, and wool, it was necessary to ascertain, by calculation, which of these products promised to give the greatest return to the breeder, and thus assist him in deciding on a breeding policy. The market conditions and current prices have been taken as a basis for the calculation. The gross receipts, composed of the income from the sale of milk, lamb, and wool, had to be correlated with the income from each of these items.

The most significant coefficient was that between the standard milk-yield and the gross receipts, indicating that milk production is the most important item in the gross income from a ewe in Cyprus. This highly significant figure also shows that the method of calculating the standard yield of milk is of practical value, as it permits a better classification of the ewes in regard to milk-production. The actual yield of milk, without the standard correction, also gave a significant correlation coefficient.

The income from the sale of the lamb gave a coefficient of $r = +0{\cdot}2903$, whereas the income from the sale of wool gave a coefficient of $r = +0{\cdot}1803$, indicating the minor importance of wool-production.

TABLE 10. *Correlation Coefficients for Gross Receipts and Yields*

(n : 261)

	r	S.E.
Gross receipts—standard milk yield	+0·8505	0·0171
,, —milk yield	+0·8123	0·0211
,, —income from sale of lamb . . .	+0·2903	0·0567
,, — ,, ,, wool . . .	+0·1803	0·0600
Milk yield — ,, ,, lamb . . .	−0·3128	0·0558
Standard milk yield—income from sale of lamb . .	+0·1678	0·0601

The correlation between actual milk yield and income from the sale of lamb gave a negative coefficient, confirming that ewes which suckled their lambs for a longer time gave a smaller quantity of milk for sale, whereas the correlation between standard milk yield and sale of lamb gave a positive coefficient, demonstrating that ewes which produce more milk also produce heavier lambs.

From the above correlations the following facts emerge:

1. In breeding Cyprus fat-tailed sheep, selection for increase in milk yield is of prime importance.

2. To increase profits, the ram-lambs from ewes with good milk-production should, except for a few required for breeding, be sold when they are 4 weeks old in order to obtain more milk for sale. The ewe-lambs of the best milkers should naturally be reared in order to improve gradually the milk-production of the flock.

3. For ewes giving a medium milk-production it would appear to be better to allow the lambs to suckle for at least 8–10 weeks and then sell them. The lamb will suckle more milk, which will be converted into meat, than would probably be obtained by milking the ewes during this extra period of 4–6 weeks.

4. Poor milkers, which usually also produce poor lambs, should be fattened and sold for slaughter, since it is often possible to obtain better prices for fattened ewes than for average milk-ewes.

5. The production of wool, the income from which is not great, should be considered only so far as it does not conflict with milk-production.

6. The flock-book should contain as many of these data as possible over a number of years, so that the value of every ewe can be easily ascertained. Selection on the lines indicated above should therefore eventually increase the profits from the flock.

Summary

1. A description is given of the Cyprus fat-tailed breed of sheep, especially in regard to their body-conformation, productivity, and profitableness, and the correlation between certain body-measurements and productivity has been investigated.

2. The breed compares very favourably with similar breeds in the Near East in body-development, especially in length of body and chest-measurements.

3. Productivity shows considerable individual variation, especially in milking capacity, thus indicating the possibility of rapid improvement by selective breeding.

4. No significant correlation was found between body-measurements and productivity, the only positive correlation coefficient (that between height at withers and milk yield) being on the border-line of significance.

5. Correlation between certain body-measurements and the live-weight of the animal has shown the importance of the development of chest-measurements as well as of height and length of body.

6. A method of standardizing milk yields to eliminate unequal suckling-periods is described, and its usefulness in computing the profit obtained from every ewe is shown.

7. The value of a system of recording the total income per ewe is indicated as a means of increasing profits from a flock.

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I wish to express my thanks also to Dr. W. Bruenn, Hadera, Palestine, Managing Director of the Cyprus Farming Co., who kindly permitted the use of the flock at the Kouklia Farm for these investigations.

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APPENDIX. SPECIMEN SHEET FROM LOOSE-LEAF STOCK NOTE-BOOK

CYPRUS FARMING Co. LTD.

KOUKLIA—FARM

EWE No. 440

Flock-book-number A/9

Origin Tricomo 7. xi. 35

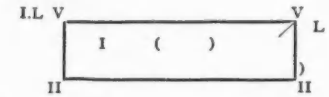
Year of birth 1932

Sire's No. ..... Dam's No. .....

BODY MEASUREMENTS

	abs. cm.	in % of H. at W.
Height at withers	67	100·0
Height at back	68	101·5
Height at crupper	68·5	102·2
Length of body	67	100·0
Depth of chest	34·5	51·5
Breadth of chest	24·5	36·6
Breadth of pelvis	29·5	44·0
Chest circumference	79	147·8
Shin-bone circumference	8	11·9
Length of head	21	31·3
Breadth of head	12·5	18·6
Live weight in kg.	47·7	

Colour: Head, yellow; legs, yellow and fettered; pasterns, yellow-coloured.



Photograph of Animal

MILK

1. Test-Milkings:

Date	Kg.	Date	Kg.
15.i.	0·930–936–	1.ii.	0·780
15.ii.	0·725	29.ii.	0·815
15.iii.	0·900	1.iv.	0·760
15.iv.	0·800	1.v.	0·590
15.v.	0·565	1.vi.	0·455
15.vi.	0·440	28.vi.	0·340
3.vii.	0·150	7.vii. last milking day.	

Y.: 127·0 kg. 187 D. 18/5½

SY.: 123·3 kg. 183 D.

6.ii.	0·745–937–	21.ii.	0·725
8.iii.	0·750	22.iii.	0·915
5.iv.	0·790	19.iv.	0·580
7.v.	0·550	17.v.	0·505
31.v.	0·260	17.vi.	0·250
28.vi.	0·130	2.vii. last milking day.	

Y.: 88·8 kg. 148 D. 22/6½

SY.: 97·0 kg. 159 D.

2. Total yield:

Year	Kg.	Year	Kg.
1936	127·0		
1937	88·8		

LAMBINGS

Sire's No.		
Date of birth	8.xii.35	25.xii.36
Date of weaning	3.i.36	4.ii.37
kg. at birth	5	5
kg. at sale	10·25	11·5
kg. at weaning		
Sex	♀	♂
Disposal	S. 6/5	S. 10/2

WOOL

1. Covered with wool:
   (*a*) Parts of head — not
   (*b*) Fore-chest — yes
   (*c*) Length of wool — 27 cm.
2. Fleece weight:

Date	Kg.	Date	Kg.
15 cp. 2.iv.36	1·900		
23 cp. 6.iv.37	1·350		

CLASSIFICATION

	Points
Milk (10)	10
Lambing (5)	4
Wool (5)	4
Body conformation (5)	5
Total	23

Disposal:

Remarks:

G.R.—Receipts: 1936: M: 18/5½; L: 6/6; W: 1/7 = £1 6 6½
1937: M: 22/6½; L: 10/2; W: 2/5 = £1 15 1½

Note.—The rectangular figure and the signs in column, situated above the space for the photograph, represent a shorthand description of the salient points of the animal. Thus the brackets in the middle mean that it has well-sprung ribs, and the bracket outside the lower right-hand corner that it has a well-developed dewlap.—Edit.

THE RELATIVE VALUES OF ORGANIC AND INORGANIC NITROGEN FERTILIZERS

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THE aim of the experiments described in this paper was to obtain further information on the relative effects of organic and inorganic nitrogen fertilizers since, although experiments have failed to show that organic nitrogen fertilizers possess any intrinsic superiority over inorganics, many horticulturists adhere to the view that organics are superior.

The experimental work described consists of two parts. In the first part, the results of a field experiment under typical market-garden conditions are described, and in the second, the results of a parallel pot-culture experiment carried out under controlled conditions are given.

In this paper, by the term 'organic nitrogen fertilizers' or, in short, 'organics', is meant those materials of plant or animal origin which contain a fairly high proportion of plant nutrients, and can thus be classed as fertilizers. Bulky organic materials of low analysis, such as farmyard manure, do not come in this category.

I. *Field Experiment with Brussels Sprouts*

The field experiment was conducted at Datchet, Bucks., on the same site in 1934 and 1935, on alluvial soil in very good heart and typical of the market gardens in the neighbourhood. The crop used in the experiment was brussels sprouts. In 1932 a crop of oats, undersown with seeds, was taken, and in 1933 a seeds crop, which was very good and contained a high proportion of clover.

Weather conditions.—Monthly figures for rainfall and sunshine are given in Table 1. The percentage moisture-contents of soil samples (0–6 in.), taken at the same time as the plant-samples referred to below, are also included in the table; determinations of moisture were made at the end of each month, except in April–July 1935, when they were made in the middle of the month.

Treatments.—In Table 2 details of the materials studied are given, together with their analyses and the rates of application of nitrogen each year.

The basis of the rates of application was the amount of nitrogen contained in a dressing of 15 cwt. of crushed hoof per acre. All the materials except shoddy were in a fine state of division. The shoddy was fine and short, contained no lumps, and was of low bushel-weight. The soot and shoddy were forked into the top 9 in. of soil about two weeks before the other nitrogenous materials were applied and worked into the top 6 in. of soil with Buco cultivators.

In 1934, 25 cwt. superphosphate and 7 cwt. sulphate of potash per acre were applied in May to all plots; in 1935, 10 cwt. superphosphate

and 5 cwt. sulphate per acre were applied in May to all plots. These heavy dressings were given not only to avoid deficiencies, but to swamp the effects of any phosphate or potash in the organic fertilizers.

TABLE 1. *Weather Records*

	1934			*1935*		
	Rainfall inches	*Sunshine hours*	*Soil-moisture %*	*Rainfall inches*	*Sunshine hours*	*Soil-moisture %*
January	1·470	18·5	..	0·808	21·3	..
February	0·128	65·9	..	2·252	48·5	..
March	2·142	107·1	..	0·540	115·2	19·8
April	1·528	129·3	14·9	2·943	121·75	13·3
May	0·392	184·0	9·3	1·202	190·0	18·1
June	1·120	204·25	9·3	4·045	187·4	12·9
July	1·505	262·2	11·3	1·390	265·9	9·6
August	2·710	164·3	17·0	1·850	186·4	17·7
September	1·412	167·0	11·3	3·655	151·8	18·1
October	1·578	64·7	12·0	2·690	104·0	16·5
November	2·082	18·7	16·9	4·535	56·3	19·0
December	5·562	6·3	18·0	0·240	20·1	19·2

TABLE 2

No.	*Treatment*	*N applied lb. per acre*	*Analysis*		
			N %	P_2O_5 %	K_2O %
1	Crushed hoof	247	14·70	..	0·27
2	Meat-and-bone meal	247	5·40	15·95	0·41
3	Shoddy	247	6·82	0·28	0·85
4	Fish-meal	247	6·76	8·29	0·75
5	Soot	247	4·51	..	..
6	Dried blood	247	14·04	0·20	..
7	Peruvian guano	247	12·68	12·28	2·30
8	Sulphate of ammonia (S/A.4)	247	20·6	..	..
9	„ „ (S/A.3)	185·25	20·6	..	..
10	„ „ (S/A.2)	123·5	20·6	..	..
11	„ „ (S/A.1)	61·75	20·6	..	..
12	No nitrogen	..	..	..	..

Each treatment was replicated six times. Individual plots contained 144 sprout plants spaced 3×3 ft., i.e. each covered approximately 1/34th of an acre.

In 1934 the crop was transplanted one month, and in 1935 it was transplanted about three months, after the soot and shoddy were applied. The date of transplanting was June 11 in both years.

As it was found in 1934 that the plots were acid, CaO, equal to the theoretical lime-requirement per plot (range, 0·35–1·85 t. $CaCO_3$ per acre–9 in.), was applied in February 1935. As soil samples taken in April and May 1935 showed that this application of lime had not raised

the pH to 7 (fertilizers having been applied in the meantime) a further 1 ton of $CaCO_3$ per acre was applied to all plots on June 5.

Plant-sampling.—In order to study the relative rates of growth under the various treatments, plant-samples were taken at intervals. One-half of each plot was treated in the normal market-garden manner (i.e. the sprouts were picked when they reached a marketable size and the lower leaves were stripped off as necessary), whilst on the other half-plot, which was reserved for taking samples, the sprouts were not picked and the lower leaves were not removed, i.e. the sample plants were complete except for some natural leaf-fall at the end of the season.

Six plants were taken at random, one from each of six rows, at monthly intervals from each 'sample' half-plot. In 1934 the plants were divided into (i) leaves and sprouts, and (ii) stems and roots, and, after being weighed, samples were taken from each half-plot for dry-matter and nitrogen determinations. In 1935 the plants were divided into (i) sprouts, (ii) leaves, and (iii) stems and roots; the produce from sets of three plots was bulked, thereby reducing the number of effective replicates to two, and dry-matter determinations and chemical analysis were conducted on these two replicates.

Results.—Since the nitrogenous fertilizers did not differentially affect the parts of the plant, and as there was very little variation in percentage dry-matter content, figures for *total* weight of dry matter and nitrogen-content of the whole plant only are given in Table 3. The yields of sprouts from the 'yield halves' of the plots are given in Table 4.

The differences between the treatments will not be discussed here, since they are considered later in relation to the soil data.

Soil data.—Soil samples were taken to a depth of 6 in. from each 'sample' half-plot at monthly intervals and were examined for contents of ammonia and nitrate (Olsen's method), total nitrogen, and for pH. Soil-moisture content was determined on bulk samples per block in 1934, but on each plot in 1935.

Ammonia and nitrate.—The results for ammonia and nitrate are shown in Fig. 1 (page 43). In considering these results, it should be borne in mind that soot and shoddy were incorporated in the top 9 in. and the other nitrogen fertilizers in the top 6 in. of soil; also that the ammonia and nitrate found in the soil represent the residues left after removal, by uptake, by the crop and micro-organisms, leaching, &c.

The results show that: (i) In both years, and for all treatments, ammonia- and nitrate-contents followed the same general trends; (ii) the average ammonia-content was lower and the nitrate higher in 1935 than in 1934 owing, no doubt, to the lime applied in 1935; (iii) the sum of ammonia plus nitrate with the organics was higher in 1935 than in 1934 owing, probably, to the lime applied in 1935; (iv) during July and August 1934 the nitrate-content was lower with sulphate of ammonia than with the organics; no such effect occurred in 1935; (v) the organics became gradually available, Peruvian guano being the quickest; and (vi) the ratio of ammonia to nitrate was higher with sulphate of ammonia than with the organics, particularly in 1934.

Total nitrogen.—Results of total-nitrogen determinations on the soil

TABLE 3. *Total Dry-matter Yields and Nitrogen-content of Crop*

1934

	Dry-matter cwt. per acre							*Nitrogen lb. per acre*						
	July 4	*Aug. 1*	*Aug. 28*	*Sept. 26*	*Oct. 24*	*Nov. 22*	*Dec. 15*	*July 4*	*Aug. 1*	*Aug. 28*	*Sept. 26*	*Oct. 24*	*Nov. 22*	*Dec. 15*
1. Crushed hoof	0·29	5·4	28·8	65·4	79·6	90·8	84·3	1·29	26·3	124	256	297	308	331
2. Meat-and-bone	0·28	5·5	30·7	68·5	81·2	96·3	90·2	1·29	26·8	129	263	274	320	337
3. Shoddy	0·29	5·0	26·8	64·8	78·0	95·5	84·3	1·37	23·6	109	216	250	331	301
4. Fish-meal	0·27	5·4	30·8	67·3	81·1	97·8	87·8	1·29	26·1	130	238	286	337	340
5. Soot	0·19	3·7	20·4	57·0	79·0	89·9	77·7	0·81	17·8	88	220	305	330	318
6. Dried blood	0·27	5·0	27·2	60·0	81·1	87·1	80·7	1·29	24·4	117	231	280	317	312
7. Peruvian guano	0·28	5·2	28·9	70·1	89·6	90·3	83·4	1·37	25·8	122	262	303	309	306
8. S/A.4	0·29	4·9	25·6	58·6	76·2	95·2	84·2	1·37	23·2	112	239	292	350	345
9. S/A.3	0·27	5·2	27·3	60·2	85·2	96·5	85·1	1·29	25·8	125	248	336	353	329
10. S/A.2	0·27	4·0	26·0	58·2	83·1	88·5	78·8	1·29	19·1	108	220	316	301	314
11. S/A.1	0·29	4·2	24·6	54·9	72·7	84·0	75·7	1·29	19·9	103	203	242	282	276
12. No nitrogen	0·27	5·2	28·2	61·7	74·4	94·0	76·9	1·29	24·8	111	209	237	297	263
Standard error	0·026	0·43	1·37	3·17	3·74	4·61	1·87							

1935

	Dry-matter cwt. per acre						*Nitrogen lb. per acre*					
	Aug. 1	*Sept. 2*	*Sept. 30*	*Oct. 28*	*Nov. 25*	*Dec. 19*	*Aug. 1*	*Sept. 2*	*Sept. 30*	*Oct. 28*	*Nov. 25*	*Dec. 19*
1. Crushed hoof	5·70	29·2	48·6	69·4	62·1	54·8	25·2	133	194	269	270	213
2. Meat-and-bone	7·05	31·8	50·4	62·6	66·4	56·6	32·8	135	185	235	276	248
3. Shoddy	7·10	28·3	53·8	63·8	63·8	55·6	30·8	122	177	215	241	230
4. Fish-meal	6·30	29·3	53·6	60·7	64·7	60·8	28·4	129	181	221	269	257
5. Soot	4·80	19·3	42·8	60·4	54·5	50·6	22·0	89	170	230	231	224
6. Dried blood	6·95	27·8	53·3	62·5	69·5	55·3	32·0	145	213	247	282	244
7. Peruvian guano	7·25	26·5	47·3	63·2	62·1	54·0	34·0	113	179	236	278	226
8. S/A.4	4·75	25·9	47·2	55·5	66·4	56·7	21·6	114	181	213	281	244
9. S/A.3	5·65	24·7	46·3	60·4	60·5	53·1	27·2	107	176	221	243	239
10. S/A.2	6·65	24·2	45·1	60·7	61·7	54·1	30·0	110	155	215	246	220
11. S/A.1	6·10	23·2	45·0	53·5	58·0	49·6	25·2	101	154	184	216	193
12. No nitrogen	5·35	18·7	43·5	52·5	52·1	53·5	20·8	72	128	155	172	191
Standard error	0·886	2·18	3·65	3·12	2·46	2·53	3·59	15·54	18·66	8·73	5·34	29·48

TABLE 4. *Yields of Fresh Sprouts (cwt. per acre)*

1934

	Total, including 'Blowers'						*Marketable Sprouts*					
	Sept. 18	*Oct. 10*	*Oct. 17*	*Nov. 13*	*Dec. 15*	*Total*	*Sept. 18*	*Oct. 10*	*Oct. 17*	*Nov. 13*	*Dec. 15*	*Total*
1. Crushed hoof	10·1	27·2	9·9	17·7	12·1	76·9	7·7	26·9	9·9	17·7	12·1	74·2
2. Meat-and-bone	11·6	28·9	10·3	17·4	11·5	79·7	9·9	28·1	10·3	17·4	11·5	77·1
3. Shoddy	11·0	25·3	9·6	18·5	11·7	76·0	8·9	24·7	9·6	18·5	11·6	73·3
4. Fish-meal	14·6	30·2	9·9	17·5	11·1	83·3	12·4	29·7	9·9	17·5	10·9	80·3
5. Soot	9·7	21·5	8·5	18·1	10·2	68·0	7·4	20·9	8·5	18·1	10·0	64·9
6. Dried blood	11·4	23·7	9·2	18·3	11·2	73·7	9·7	23·2	9·2	18·3	11·1	71·5
7. Peruvian guano	11·9	27·0	10·0	17·3	10·9	77·0	9·4	26·5	10·0	17·3	10·7	73·9
8. S/A.4	9·0	24·8	9·3	18·2	11·2	72·4	7·1	24·4	9·3	18·2	11·1	70·1
9. S/A.3	9·2	25·1	10·7	18·2	10·9	74·0	7·5	24·6	10·7	18·2	10·8	71·7
10. S/A.2	9·4	23·1	10·0	17·2	11·0	70·7	8·0	22·7	10·0	17·2	10·9	68·9
11. S/A.1	7·9	21·0	9·2	16·1	11·8	66·0	6·5	20·4	9·2	16·1	11·6	63·8
12. No nitrogen	9·1	22·8	9·1	18·0	11·6	70·6	7·3	22·7	9·1	18·0	11·4	68·6
Standard error	1·2	1·59	0·66	0·82	0·53	2·60	..	..	0·66	0·82	..	2·53

1935

	Total, including 'Blowers'[1]					*Marketable Sprouts*				
	Oct. 10	*Oct. 21*	*Nov. 6*	*Dec. 6*	*Total*	*Oct. 10*	*Oct. 21*	*Nov. 6*	*Dec. 6*	*Total*
1. Crushed hoof	15·6	7·4	8·2	10·2	41·3	9·9	6·1	7·0	10·2	33·2
2. Meat-and-bone	17·8	7·0	7·8	9·4	42·0	11·9	6·1	6·9	9·4	34·5
3. Shoddy	21·2	7·8	9·9	11·1	50·1	12·9	6·6	8·6	11·1	39·2
4. Fish-meal	20·3	8·7	7·7	9·7	46·4	12·1	7·5	6·7	9·7	36·0
5. Soot	15·0	6·9	8·1	10·2	40·2	8·0	5·7	6·9	10·2	31·0
6. Dried blood	14·6	8·6	8·1	10·2	41·6	8·6	7·5	6·7	10·2	32·9
7. Peruvian guano	18·3	8·2	7·7	11·4	45·5	11·2	7·1	6·6	11·4	36·2
8. S/A.4	13·7	7·5	8·1	10·8	40·1	7·8	6·6	6·9	10·8	31·9
9. S/A.3	16·8	7·1	8·2	9·9	42·0	9·4	6·2	6·9	9·9	32·4
10. S/A.2	15·9	8·0	8·3	10·5	42·6	9·7	7·0	7·0	10·5	34·1
11. S/A.1	13·9	5·5	7·2	8·4	35·0	9·5	4·7	6·4	8·4	28·9
12. No nitrogen	14·0	6·9	7·1	8·8	36·8	9·4	5·9	6·1	8·8	30·2
Standard error	1·3	0·82	0·70	0·57	..	1·17	..	..	0·57	1·69

[1] Except for 6 December, when blowers were not picked.

(top 6 in.) are given in Table 5. Considerable decreases of nitrogen occurred during the growing-seasons of 1934 and 1935. Whilst these decreases were partly due to uptake by the crop, losses by leaching also occurred. The average amount of nitrogen in the crops was about 300 lb. per acre in each year, corresponding to an annual decrease of about 0·008 per cent. in the total-nitrogen content of the soil. Several of the decreases in nitrogen-content of the soil were less than

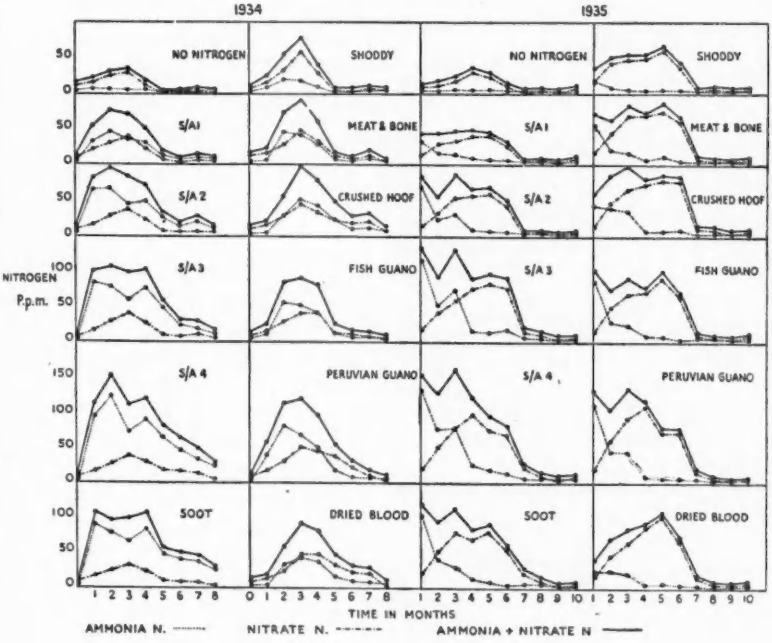

FIG. 1. Ammonia- and nitrate-nitrogen contents of soil.

0·008 per cent., and it is thus clear that the crop derived some of its nitrogen from the lower layers of the soil, unless very considerable upward movement of nitrogen occurred, and this is most unlikely.

From Fig. 2 it will be seen that the decreases in nitrogen in the top soil were proportional to the average amounts of nitrate in the soil. This would be expected, since loss by leaching would fall on the nitrate, and it is probable that the crop assimilated nitrate in preference to other forms of nitrogen.

Soil reaction.—The pH-figures are given in Table 3. The soil was at first slightly acid, but liming appeared to be unnecessary. Between the samplings taken on May 9 and June 6, 1934, a heavy basal dressing of superphosphate and sulphate of potash and the nitrogenous manures were applied. A marked fall in pH occurred in June and July, and was

1 Except for 6 December, when blowers were not picked.

TABLE 5. *Percentage Nitrogen-Content of Soil*

1934

	May 9	*June 6*	*July 4*	*Aug. 1*	*Aug. 29*	*Sept. 26*	*Oct. 20*	*Nov. 22*	*Dec. 17*	*Mean June–Aug.*	*Mean Oct.–Dec.*	*Decrease*
1. Crushed hoof	0·172	0·182	0·186	0·183	0·179	0·178	0·177	0·177	0·17,	0·184	0·176	0·008
2. Meat-and-bone	0·180	0·192	0·199	0·194	0·178	0·187	0·188	0·183	0·186	0·195	0·186	0·009
3. Shoddy	0·176	0·185	0·187	0·187	0·183	0·179	0·182	0·187	0·181	0·186	0·183	0·003
4. Fish-meal	0·182	0·198	0·196	0·192	0·199	0·186	0·189	0·188	0·189	0·195	0·189	0·006
5. Soot	0·172	0·182	0·184	0·185	0·183	0·180	0·180	0·179	0·182	0·184	0·180	0·004
6. Dried blood	0·179	0·186	0·195	0·195	0·193	0·192	0·190	0·187	0·179	0·192	0·185	0·007
7. Peruvian guano	0·176	0·194	0·206	0·192	0·189	0·187	0·184	0·182	0·184	0·197	0·183	0·014
8. S/A.4	0·178	0·184	0·197	0·192	0·191	0·189	0·189	0·182	0·180	0·191	0·184	0·007
9. S/A.3	0·172	0·180	0·185	0·183	0·183	0·181	0·178	0·176	0·175	0·183	0·176	0·007
10. S/A.2	0·174	0·176	0·184	0·179	0·180	0·177	0·175	0·174	0·175	0·179	0·175	0·007
11. S/A.1	0·176	0·183	0·184	0·185	0·181	0·180	0·179	0·179	0·182	0·184	0·180	0·004
12. No nitrogen	0·173	0·178	0·180	0·174	0·171	0·176	0·175	0·175	0·174	0·177	0·175	0·002

1935

	April 16	*May 13*	*June 12*	*July 10*	*Aug. 7*	*Sept. 3*	*Oct. 2*	*Oct. 28*	*Nov. 25*	*Dec. 19*	*Mean April–June*	*Mean Oct. 28–Dec.*	*Decrease*
1. Crushed hoof	0·189	0·182	0·188	0·177	0·174	0·173	0·166	0·170	0·167	0·163	0·186	0·167	0·019
2. Meat-and-bone	0·194	0·187	0·192	0·189	0·185	0·178	0·179	0·181	0·178	0·179	0·191	0·179	0·012
3. Shoddy	0·182	0·186	0·183	0·187	0·179	0·176	0·175	0·174	0·185	0·176	0·184	0·178	0·006
4. Fish-meal	0·194	0·189	0·193	0·189	0·187	0·182	0·181	0·181	0·181	0·181	0·192	0·181	0·011
5. Soot	0·181	0·177	0·184	0·179	0·175	0·174	0·169	0·173	0·172	0·174	0·181	0·173	0·008
6. Dried blood	0·199	0·189	0·194	0·189	0·183	0·179	0·177	0·178	0·178	0·176	0·194	0·177	0·017
7. Peruvian guano	0·190	0·181	0·189	0·183	0·182	0·178	0·173	0·173	0·173	0·177	0·187	0·174	0·013
8. S/A.4	0·186	0·180	0·188	0·183	0·182	0·177	0·173	0·172	0·173	0·172	0·185	0·172	0·013
9. S/A.3	0·178	0·172	0·181	0·178	0·173	0·172	0·166	0·169	0·166	0·167	0·177	0·167	0·010
10. S/A.2	0·172	0·170	0·173	0·174	0·170	0·163	0·163	0·166	0·162	0·161	0·172	0·163	0·009
11. S/A.1	0·174	0·175	0·177	0·177	0·173	0·174	0·164	0·170	0·170	0·172	0·175	0·171	0·004
12. No nitrogen	0·167	0·168	0·168	0·170	0·168	0·164	0·164	0·170	0·163	0·160	0·168	0·164	0·004

common to all plots, including the control. This fall was, no doubt, due to cationic exchange between the inorganic salts added and the colloid complex of the soil. The decrease in pH was somewhat greater with sulphate of ammonia and soot than with the organics, as would be

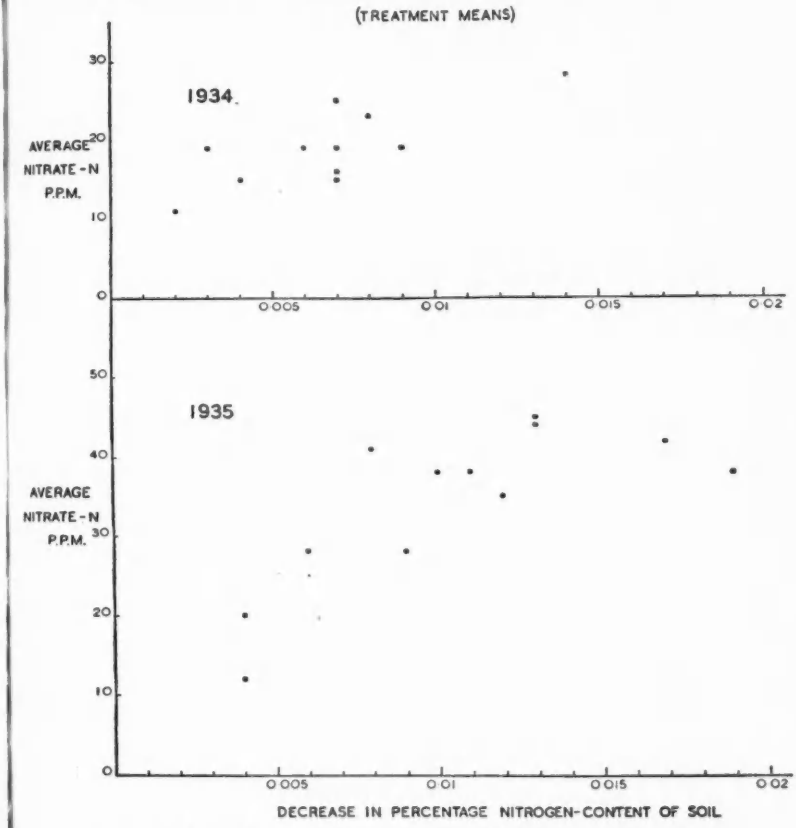

FIG. 2. Relation between nitrate-content and decrease in total-nitrogen content of soil.

expected. The relatively small decrease in pH with Peruvian guano was probably due to the rapid formation of ammonium carbonate.

All the nitrogen-treatments show a greater seasonal decrease in pH than the controls; this is no doubt the outcome of nitrification. The treatments with sulphate of ammonia and soot resulted, as would be expected, in a greater decrease in pH than the organics.

Since the soil was appreciably acid in 1934, and since yields were related to pH (see below), quicklime was applied in February 1935 to each plot at a rate corresponding to its theoretical lime-requirement [1].

TABLE 6. *pH Values of Soil*

1934

	May 9	*June 6*	*July 4*	*Aug. 1*	*Aug. 28*	*Sept. 26*	*Oct. 24*	*Nov. 22*	*Dec. 15*	*Mean (arith.)*
1. Crushed hoof	6·07	5·67	5·61	5·80	5·90	5·53	5·47	5·49	5·69	5·69
2. Meat-and-bone	6·45	5·91	6·05	5·93	6·22	5·93	5·95	5·89	6·11	6·06
3. Shoddy	6·63	6·13	6·06	6·02	6·07	6·07	6·33	6·21	6·31	6·20
4. Fish-meal	6·54	6·03	6·20	6·11	5·97	5·90	5·84	5·97	6·16	6·08
5. Soot	6·36	5·70	5·67	5·70	5·64	5·60	5·50	5·56	5·72	5·72
6. Dried blood	6·43	5·96	5·99	5·98	5·82	5·69	5·77	5·86	6·03	5·95
7. Peruvian guano	6·30	5·97	6·08	5·98	5·82	5·75	5·76	5·94	5·97	5·95
8. S/A.4	6·32	5·72	5·77	5·71	5·46	5·44	5·19	5·30	5·44	5·60
9. S/A.3	6·30	5·74	5·65	5·94	5·44	5·35	5·27	5·38	5·58	5·63
10. S/A.2	6·30	5·69	5·66	5·98	5·48	5·39	5·28	5·44	5·59	5·55
11. S/A.1	6·04	5·59	5·55	5·60	5·49	5·51	5·38	5·52	5·54	5·58
12. No nitrogen	6·05	5·56	5·69	5·60	5·57	5·63	5·67	5·74	5·96	5·72
Moisture %	14·9	9·3	9·3	11·3	17·0	11·3	12·0	16·9	18·6	..

1935

	April 16	*May 13*	*June 12*	*July 10*	*Aug. 7*	*Sept. 3*	*Oct. 2*	*Oct. 28*	*Nov. 25*	*Dec. 19*	*Mean (arith.)*
1. Crushed hoof	6·52	6·29	6·63	6·32	6·70	6·33	6·62	7·06	7·13	7·04	6·73
2. Meat-and-bone	6·85	6·38	6·94	6·76	6·76	6·68	6·97	7·36	7·55	7·43	7·06
3. Shoddy	6·69	6·41	7·03	6·85	6·78	6·79	7·07	7·43	7·57	7·44	7·12
4. Fish-meal	6·77	6·48	6·88	6·65	6·71	6·57	6·90	7·26	7·35	7·33	6·94
5. Soot	6·33	5·97	6·42	6·22	6·19	6·29	6·46	6·84	7·02	7·08	6·57
6. Dried blood	6·58	6·27	6·85	6·65	6·43	6·47	6·69	7·09	7·29	7·08	6·83
7. Peruvian guano	6·95	6·42	6·78	6·61	6·53	6·67	6·80	7·19	7·38	7·28	6·91
8. S/A.4	6·37	6·16	6·28	6·40	6·01	6·06	6·09	6·51	6·43	6·79	6·32
9. S/A.3	6·24	6·14	6·62	6·18	6·35	6·04	6·31	6·50	6·96	6·90	6·48
10. S/A.2	6·13	6·02	6·55	6·39	6·31	6·24	6·50	7·06	7·13	7·13	6·66
11. S/A.1	6·27	6·09	6·72	6·59	6·46	6·48	6·54	7·20	7·33	7·21	6·82
12. No nitrogen	6·41	6·35	6·91	6·69	6·61	6·65	6·90	7·12	7·47	7·35	6·98
Moisture %	19·8	13·3	18·1	12·9	9·6	17·7	18·1	16·5	19·0	19·2	..

After this dressing of lime, the fertilizers were applied, and the pH-values dropped. A further dressing of lime ($CaCO_3$ at the rate of 1 ton per acre) was therefore applied to all plots on June 5. The figures for October–December indicate that sufficient lime had been applied to bring the soil to neutrality in the winter.

Relation between crop yields and soil data.—There are no indications of a general relation between yields of sprouts and the ammonia- or nitrate-content of the soil, but the average treatment yield-differences show a relation to average treatment pH-differences. The relation between crop yield (total yield of marketable sprouts) and soil pH is, therefore, studied in detail. The results for the first ten treatments only are used below, since inclusion of treatments 11 and 12, S/A.1 and no nitrogen, which suffered from lack of nitrogen in 1935, might tend to confuse the issue. As a parallel to the plot-figures available for pH, modified analyses of variance for the yield-figures (marketable sprouts, total fresh weight, lb. per plot) are given in Table 7, the yields from pairs of blocks having been pooled. The variance for error obtained from the original full analysis is also given in brackets.

TABLE 7

	1934			*1935*		
	D.F.	*S.S.*	*Variance*	*D.F.*	*S.S.*	*Variance*
Treatments . .	9	2778·1	308·68	9	914·26	101·58
Blocks . . .	2	3276·1	1638·05	2	351·68	175·84
Error . . .	18	940·0	52·22	18	914·80	50·82
(Full error) . .	(54*)	(5762·7)	(106·72)	(55)	(2618·66)	(47·61)
Total . .	29	6994·2	..	29	2180·74	..

* The yield for one plot estimated.

The treatment differences in 1935, though not reaching significance when compared with the error-term of 18 d.f., are significant when compared with the original error-term of 55 d.f. The differences in 1934 are highly significant when compared with either term. It will be noticed that in 1934 the original error-term appears much larger than the modified one, and the discrepancy is, in fact, significant. This is presumably due to a real block × treatment interaction, which is diminished when the pairs of blocks are pooled; this seems in accordance with the very large block-differences observed in 1934.

The extent of the relationship of yield with pH of soil is indicated by division of the treatment degrees of freedom into a term representing the extent to which these differences appear expressible in terms of pH (Table 8).

In 1935, allowance for pH eliminates practically all the variation, the remainder-variance being insignificant. Allowance for pH also eliminates a large part of the variation in 1934, but the remainder-variance is relatively high. It is suggested that this relatively high remainder-variance, after allowance for pH in 1934 (Table 8), may be connected

with the fact that the ratio of ammonia to nitrate in the soil was particularly high with sulphate of ammonia in the early stages, owing to soil acidity.

TABLE 8

		1934		*1935*	
	D.F.	*S.S.*	*Variance*	*S.S.*	*Variance*
Regression on pH . .	1	1078·8	1078·8	593·45	593·46
Remainder . . .	8	1699·3	212·4	320·80	40·10

The relation between pH and yield extends right through the individual plot-data in both years and is particularly marked in 1935 ($r = +0{\cdot}7231$). A complete analysis of covariance on the plot-yields for 1935 thus reveals no treatment-differences when adjustment for plot pH-values is made (Table 9).

TABLE 9. *Yields in 1935 adjusted for pH*

	D.F.	*S.S.*	*Variance*
Treatments	9	334·82	37·20
Blocks	2	57·84	28·92
Error	17	690·84	40·64
Error-regression	1	223·96	223·96

II. *Pot-Culture Experiment*

The experiment was conducted in glazed pots, using, as growth-medium, a mixture of soil from the experimental field at Datchet, and sand. White mustard (*Sinapis alba*) was used as the test plant in the first year, several immature crops being harvested to study uptake of nitrogen in the early stages of the experiment. Barley and buckwheat were used in the second and third years.

The treatments were the same as in the field experiment, with the addition of urea and ammonium nitrate. The basis of the rate of application was 15 cwt. crushed hoof per acre (0·68 gm. nitrogen per pot). All pots received the equivalent of 20 cwt. superphosphate and 7 cwt. sulphate of potash per acre. The pots were arranged in six random blocks each containing 48 pots (16 treatments[1] × 3 times of harvesting).

Results.—In order to simplify the presentation of the data, the results from two or more mustard crops have been averaged when their mean nitrogen-uptakes were approximately the same. Summation figures for nitrogen-contents (uptake) are given in Table 10, and the percentage recoveries of applied nitrogen are shown in Fig. 3. Yields of dry matter are not given, as they were closely related to nitrogen-uptake, except in the very early stages when the nitrogen fertilizers caused a marked increase in the percentage nitrogen-content of the dry matter.

The results afford no evidence whatever of any advantage of organics over inorganics. The curves show the relative rates of availability of the nitrogen in the different fertilizers. The recovery of nitrogen with

[1] Including 3 controls (no nitrogen).

the inorganics (ammonium nitrate and ammonium sulphate) was approached only by that with Peruvian guano and urea. Of the other organics, shoddy was the slowest, except in the early stages when the recovery with soot was negative, suggesting the presence of a toxic

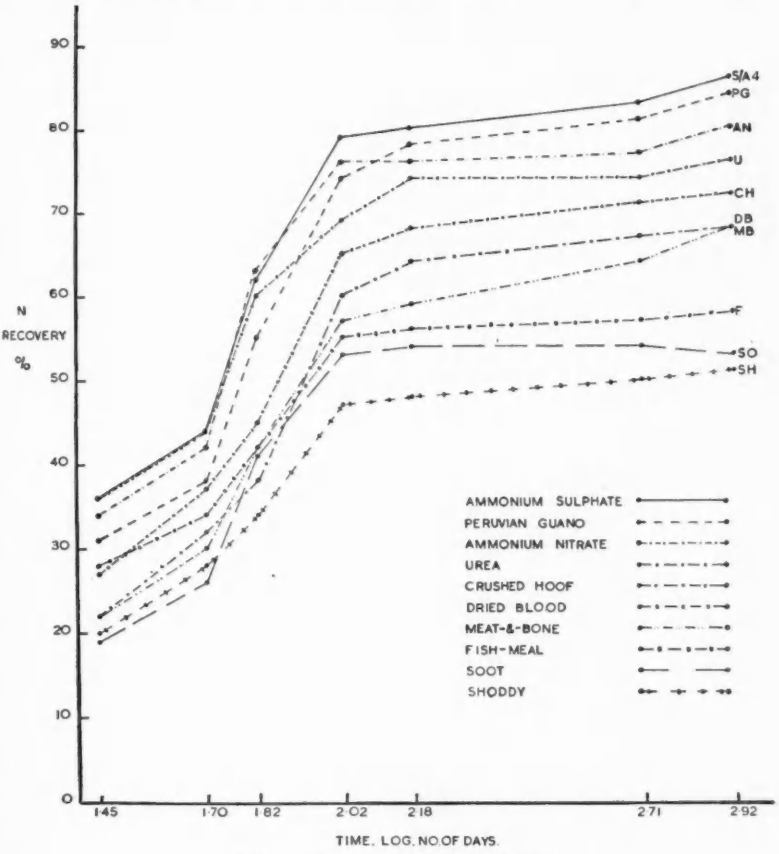

FIG. 3. Recovery of added nitrogen.

component. This harmful effect of soot in the early stages of the experiment is surprising in view of its wide use in practice. The soot used was household soot, obtained from a reputable firm and guaranteed to have been stored for a year.

There are no signs of the recoveries with the organics, except Peruvian guano and urea, approaching those with the inorganics, and the flattening of the curves (Fig. 3) after about 150 days suggests that the recovery of added nitrogen was approaching completion in all cases. The low recoveries of nitrogen with some of the organics cannot be

attributed to unfavourable physical condition of the soil, since the soil was removed from the pots, thoroughly mixed in the spring of 1935 and of 1936, and the soil-moisture content was maintained at an optimum while the crops were growing.

Effect of fertilizers on soil reaction.—The results of pH-determinations made on the soil-sand mixture at the end of the experiment are given in Table 10. The pH of the medium was 6·51 when the experiment began.

TABLE 10. *Uptake of Nitrogen (gm. per pot) and pH. values of 'Soils' at end of Experiment (Arithmetic Means)*

Days from start of experiment	*17*	*25*	*38*	*50*	*66*	*104*	*150*	*510*	*830*	*pH*
Soot . .	0·0146	0·068	0·211	0·285	0·395	0·529	0·566	0·619	0·657	5·99
Shoddy .	0·0180	0·084	0·220	0·297	0·346	0·480	0·523	0·584	0·640	6·11
Fish-meal .	0·0199	0·087	0·269	0·339	0·401	0·540	0·580	0·638	0·690	6·18
Meat-and-bone	0·0202	0·084	0·231	0·310	0·400	0·551	0·598	0·680	0·757	6·06
Dried blood .	0·0199	0·078	0·232	0·325	0·373	0·571	0·628	0·691	0·760	6·02
Crushed hoof.	0·0216	0·082	0·261	0·359	0·419	0·609	0·658	0·728	0·786	6·37
Peruvian guano	0·0225	0·083	0·288	0·364	0·489	0·671	0·725	0·797	0·863	5·95
Urea . .	0·0241	0·085	0·327	0·406	0·522	0·666	0·702	0·753	0·814	6·18
Ammonium nitrate .	0·0234	0·089	0·313	0·393	0·547	0·680	0·715	0·769	0·840	6·18
S/A.4 . .	0·0230	0·084	0·324	0·407	0·540	0·702	0·743	0·814	0·877	5·79
S/A.3 . .	0·0231	0·092	0·289	0·357	0·444	0·536	0·569	0·631	0·681	5·91
S/A.2 . .	0·0206	0·090	0·251	0·307	0·400	0·458	0·489	0·535	0·584	5·96
S/A.1 . .	0·0201	0·086	0·171	0·213	0·239	0·301	0·334	0·383	0·430	6·17
No nitrogen .	0·0179	0·065	0·081	0·107	0·116	0·165	0·196	0·246	0·295	6·31
Standard error	0·0008	0·0033	0·0069	0·0097	0·0131	0·0113	0·0121	..	..	..

The results are more or less as expected except for crushed hoof, which gave a slightly higher pH than the control (no nitrogen), whereas a decrease might have been expected since a good deal of its nitrogen was probably converted to nitrate. The higher pH with soot than with S/A.4 indicates that much of the nitrogen in the soot was not converted to nitrate.

The fact that there is no correlation between soil acidity and yield is very probably due to any slightly harmful effect of increased acidity being swamped by the beneficial action of nitrogen.

Discussion

The results of the field experiment and the pot experiment show that organic fertilizers had no intrinsic advantage over inorganic fertilizers and, provided that the lime-status of the soil is maintained at an adequate level, inorganic fertilizers will give at least as good, and probably better, results than organic fertilizers.

The main claims for the superiority of organics are: (i) the slow release of nitrogen from them in an available form means that nitrogen is supplied in just the right amounts and at just the time that it is needed by the crop; (ii) they improve the soil physically and are a source of humus; and (iii) they contain specific beneficial substances, e.g. hormones or similar substances.

Sponsors of argument (i) overlook the fact that slow release of nitrogen may be a disadvantage and not an advantage, since the rate of release of

nitrogen from organics may lag behind the needs of the crop. The mere fact that top-dressings of quick-acting nitrogen fertilizers are necessary is, in itself, proof of this. The experiments of Anderson, Morgan, and their co-workers [2, 3] on tobacco also afford very clear evidence on this point. They showed that the rate of supply of nitrogen in nitrate was very close to the needs of the plant when the nitrogen was supplied in urea, but the rate of supply of nitrate lagged behind the needs of the crop when the nitrogen was supplied as cotton-seed meal. Provided that the lime-status of the soil was maintained at an adequate level, ammonium sulphate gave about the same results as urea. With nitrate of soda the results were good in dry years and in normal years when applied in several small doses, but with single, heavy applications the results were poor in wet years. It is well known that ammonium nitrogen is fixed by the soil colloids and so protected from loss by leaching, and as the conversion of ammonia to nitrate is most rapid under those conditions of temperature and moisture which are optimum for plant-growth, it would appear that ammonium salts, or any material such as urea or Peruvian guano which *rapidly* breaks down to ammonia in soil, will be more suitable for use in basal dressings in market gardens than slow-acting organics or nitrates. Further, it would appear from the results of the Rothamsted experiments [4] and from the results here presented, that the efficiency of slow-acting organic fertilizers is probably less than that of inorganics, since some of the nitrogen in the former may be unavailable.

Regarding the claim that organics improve soil conditions, the present experiments admittedly afford no evidence on the relative effects of continued application of organics and inorganics but, as Russell [4] has pointed out, there is very little evidence for the view that organics permanently benefit the soil. Further, the results of Page and his co-workers at Rothamsted [5] indicate that lignin is an essential constituent of the humic matter in soil, so that the use of organic fertilizers of animal origin cannot directly result in the production of humic material. It seems certain that if the lime-status of the soil is maintained at an adequate level, inorganics properly used will give at least as good results as organics, and hence will lead to greater profit. This is not meant to imply that organic matter is not needed, since the opposite is clearly the case. What is implied is that whether inorganics or organics are used, the need for bulky organic matter, such as dung, will be the same.

Regarding the possible specific beneficial effect of hypothetical organic compounds, Hartley and Greenwood [6] described in 1933 the results of an experiment which seemed definitely to prove the possibility of such an effect, but Hartley [7] has since shown that this apparent specific effect was nothing more than a beneficial effect of the phosphorus in the farmyard manure. However, as Crowther [8] has pointed out, recent work on plant and animal hormones has been seized on by those who are anxious at all costs to discover some support from the traditional view that farmyard manure possesses specific virtues, transcending those which may be ascribed to its physical effects on the soil and to its

content of the commoner nutrient elements. The position is that although certain substances are known to be of considerable value in the rooting of cuttings, there is no evidence that hormones affect the yield of crops. Boysen Jensen (quoted by Crowther [8]) has expressed the view that, if the hormones which cause extension-growth in plants are produced by micro-organisms in the soil, their effect would be to reduce root-growth and dry-matter production. Further, Nehring and Mobius, also quoted by Crowther, conclude from their experiments that it is impossible to accept the view that oestrogenic substances have any special importance for agricultural crops.

Summary

The results of a field experiment and a pot experiment to study the relative effects of organic and inorganic nitrogen fertilizers show that organic nitrogen fertilizers are not superior to inorganic nitrogen fertilizers in crop-producing power. There is no evidence that organic nitrogen fertilizers have any value beyond that due to their nitrogen-content.

The evidence shows that provided the lime-status of the soil is maintained at an adequate level, inorganic nitrogen fertilizers will give at least as good results as organic nitrogen fertilizers supplying the same amounts of nitrogen.

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EXPERIMENTAL AND STATISTICAL TECHNIQUE OF SOME COMPLEX COTTON EXPERIMENTS IN EGYPT

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1. *The Experimental Programme of the Joint Agricultural Research Scheme in Egypt*

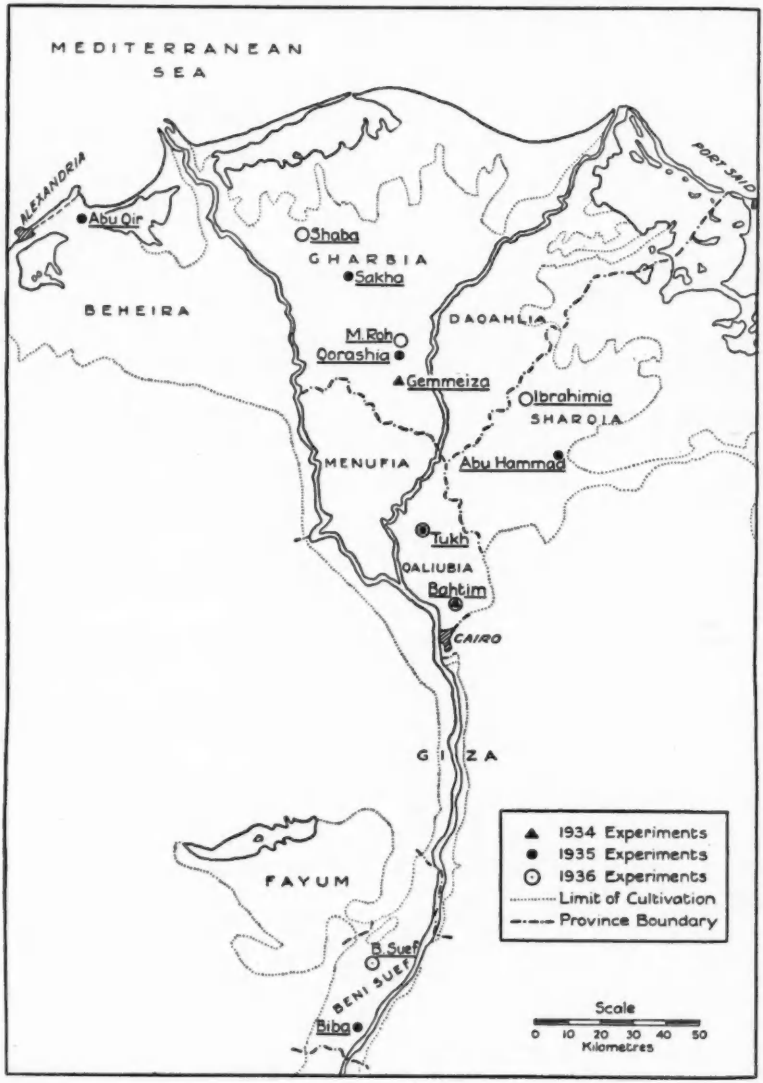
IN 1934 a series of field experiments was begun in Egypt under a Joint Agricultural Research Scheme initiated by the Royal Agricultural Society of Egypt and Imperial Chemical Industries, Limited, who were joined a year later by the I.G. Farbenindustrie Aktiengesellschaft. The yield results of these experiments are described in bulletins published by the Royal Agricultural Society of Egypt [1, 2, 3, 4, for example]. An account of these results has also been given recently in this *Journal* [5], but as it is thought that points of statistical interest arising from the lay-outs and analyses of results would also prove of value to all concerned with agricultural experimentation, a review is made here of the experiments from the standpoint of experimental technique.[1] In view of the essentially close connexion between the object of an experiment and the way it is designed, it is necessary first to mention briefly the various possible lay-outs that are familiar, and explain how the type of lay-out adopted fitted in naturally both with the objects of the Scheme and with the practical problems occurring in the actual conduct of the experiments.

Experimental lay-outs known as randomized blocks and Latin squares are by now familiar to most agriculturists, and may be regarded as the standard lay-outs for replicated experiments involving comparatively few treatments. In recent years there has, however, been an increasing recognition of the value of complex or factorial experiments, in which all combinations of more than one factor are tested simultaneously. The more common examples include experiments in which all combinations of nitrogen, phosphate, and potash are present, making in the simple case of the presence or absence of these three nutrients eight different treatments, and in the more complicated case, where each nutrient is tested both at single and double rates, twenty-seven different treatments.

It will be evident that if three or four factors, each possibly representing two or three treatments, are to be tested in the same experiment, the total number of treatment-combinations begins to get large, and if a straightforward randomized-block lay-out is used, the number of plots per block may often be prohibitive. This difficulty can sometimes be partly overcome by the device known as confounding, in which the number of plots per block is diminished without information being lost on the most important comparisons. In other cases it may be convenient to have some treatments arranged in main plots, which are further

[1] Some of the statistical aspects of the experiments have also been considered by one of the authors (M. S. B.) in a general paper on statistical problems in agriculture [6].

DISTRIBUTION OF COTTON EXPERIMENTS, 1934-1936



divided into sub-plots[1] for testing additional factors. The latter method is most useful when some treatments, such as varieties or cultivation, do not so easily lend themselves to segregation into very small plots. For further information on the factorial experiment or confounding, reference may be made to Fisher's book on the design of experiments [7].

The ideal set of experiments on a crop is obviously a comprehensive set of complex experiments carried out in a large number of different places in the country, and over a long period of years. The inevitable simplification of such an ideal scheme implies a certain loss of information, the nature of which will depend on the nature of the simplification. If fewer complex experiments are put down, less information on local and individual weather and soil variations will be forthcoming; if simpler lay-outs are used, no knowledge will be available of the effects there might have been under different cultural conditions. The compromise actually adopted must be related to the objects and nature of the investigation.

Cotton, being the most important export crop in Egypt, took first place in the experiments of the Joint Scheme. Of recent years many drastic changes have occurred in the cultivation of cotton, particularly in the Nile Delta, where the high-quality varieties are grown. These changes have arisen primarily from the spread of Pink Bollworm, which has become a major pest in all seasons, causing loss of most of the late crop. The measures taken to minimize this loss have been the introduction of early-maturing varieties, earlier sowing, and closer spacing. The farmer, accustomed to a settled system of cultivation based on tradition, has tended to treat the new varieties as he did the old ones, without regard to their individual requirements for maximum yields, and the changes have been so rapid that he has had little experimental work to guide him.

It was this set of circumstances which led to the initiation of the Joint Scheme and which dictated the type of experimental lay-outs employed. There were indications that simultaneously with the changes in variety and spacing the manurial requirements of the cotton crop were changing. Such conditions need the complex experiment for their elucidation, and the economic value of the crop coupled with the intensive farming practised in Egypt put a premium on the definition of the optimum levels of the factors and the degree of interaction between them. Before the Joint Scheme was initiated the Ministry of Agriculture had started an investigation on the interplay of factors, and the results were summarized in 1935 by Gracie and Khalil [9].

The abundance of cheap labour in tropical and sub-tropical countries and the amount of hand cultivation and harvesting employed are much more favourable to the complex experiment involving a large number of small plots than the mechanical cultivating and harvesting practised in countries like England.

After preliminary trials in 1934, several factorial experiments were put down on representative sites in 1935, and were repeated on other sites

[1] The conventional terms 'main' and 'sub-plots' are used throughout this paper, though it should perhaps be emphasized that from the experimenter's point of view the sub-plots are all individual plots treated and harvested separately.

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the following season (see map). Egyptian cotton is sown in February and March, and harvested, usually in two pickings, in August to October. Rainfall during this period is negligible, and the crop receives eight to ten artificial irrigations during growth. The intervals between irrigations vary with the time of year and are at a minimum for about 14 days during June and July. The varieties grown differ considerably in both yield and quality. Ashmouni preponderates south of Cairo and in the southern Delta, and Giza 7, Sakel, and Maarad farther north. The crop is sown on ridges spaced about 60 cm. apart at present, and for experimental purposes it is most convenient to vary the spacing along the ridge rather than the distance between ridges. Ten to fifteen seeds are dibbled into a pocket on the southern side of the ridge, and the resulting plants are thinned when seven weeks old to a final stand of two plants per hole. In the experiments the distances between holes were usually 15, 25, and 35 cm. for close, medium, and wide spacings, respectively. When manures are used phosphates are applied before sowing and nitrogenous manures at thinning time, the former broadcast on the side of the ridge, the latter in pinches at the base of each pair of plants.

The experiments were limited in the 1934 season to simultaneous comparisons of the four factors, variety, spacing, nitrogen, and water-supply. In 1935 phosphate generally replaced water as the fourth factor. As the information from the experiments proved consistent, in 1936 the investigations were extended to include such factors as date of sowing and date of fertilizer application. Only in one experiment, Bahtim 1936, were more than four factors included. The usual type of lay-out comprised 216 plots, consisting of threefold replication of 72 treatments. The area of a single plot was as near to 100 square metres as the configuration of the land would allow, and the gross area of an experiment, including belts between plots and around the experiment, was from 8 to 10 feddans.[1] Certain modifications had to be made to suit local conditions. The Biba experiment, for instance, was in a district where the superiority of Ashmouni was so well established as to rule out the inclusion of variety as a factor. The Abu Qir experiment, being situated on the bed of a drained lake, was expected to differ from experiments made under ordinary Delta conditions. As there was no information available from previous experiments, and as the cultivators, being only recently imported to this area, had no tradition to guide them, it was necessary to cover as wide a range of treatments as possible, and though the experiment was of necessity limited to 48 plots, the four factors of variety, spacing, nitrogen, and phosphate were included in it.

With the hand labour used in cotton cultivation it is possible to sow as small an area as a single plot with any one variety or any one spacing, but it is advisable to group together plots of the same treatment where sowing-dates and irrigation-treatments are involved, to avoid interference between adjacent plots and pronounced marginal effects. Thus from the point of view of feasibility, the experimenter has a wide choice of lay-outs, but it will be seen later that on many sites soil variability imposes restrictions.

[1] 1 feddan = 1·038 acres = 0·420 hectare.

2. *The Efficiency of the Lay-outs Used*

The lay-outs have been on the whole fairly straightforward statistically. The confounding of any of the higher-order interactions between the factors was rarely adopted, this type of confounding not being forced into the lay-out if inconvenient. On the other hand, the method already mentioned of using main and sub-plots (which is also a type of confounding) was sometimes used. As an example, an experiment at Bahtim in 1934 [1] consisted of four replications of all combinations of the following sets of treatments:

VARIETIES	Ashmouni Giza 7 Maarad	WATERING	Normal Heavier
SPACING	Close Medium Wide	MANURING	Nil 150 kg./feddan nitro-chalk 300 kg./feddan nitro-chalk

The varieties and watering were main-plot treatments, a main plot consisting of a strip of 9 sub-plots. There were thus four randomized blocks of 6 main plots, each set of 9 sub-plots being randomized within the main plot. The analysis of variance of this experiment will have two parts, corresponding to the main and sub-plots, each with its own error-term ([9] p. 199). This is not reproduced here; but the error-term may be quoted.

TABLE 1. *Bahtim Cotton Experiment, 1934. Analysis of Variance, Error-Terms (yields in kantars*[1]*/feddan)*

Error (sub-plot basis)	*D.F.*	*Sum of squares*	*Variance*
Main plot . . .	15	59·7715	3·9848
Sub-plot . . .	144	34·9245	0·2425
Total . . .	159	94·6960	0·5956

[1] One kantar of seed cotton per feddan = 300·6 lb. per acre = 337 kg. per hectare.

From the above table the relative efficiency of the experiment for the main and sub-plot treatments is at once estimated from the ratio of the two variances. This ratio is 16·4, indicating not only that the sub-plot treatments are much more accurately determined, but that for this experiment the ratio is even greater than the relative number 9 of sub-plots to main plots.

In the Bahtim experiment the inclusion of different watering-treatments in the main plots made it almost essential that the main and sub-plot type of lay-out should be adopted; but it is interesting to ask what changes in accuracy would have resulted on the different effects if no such division into main and sub-plots had been made, even in cases where such a modification in the lay-out would not have been practically convenient. Yates has shown how we may attempt to find the answers to such questions [9]. In the present problem his method is equivalent to determining the ratio of each variance to the mean variance, giving 6·7

for the main-plot treatments, and 0·41 for the sub-plot treatments. This means that if complete randomization without division into main and sub-plots had been made, we could have expected our information (measured in terms of effective replications) on the main-plot treatments to have been increased by 570 per cent., and on the sub-plot treatments to have been diminished by 59 per cent.

These efficiency ratios are recorded in Table 2 for the Egyptian cotton experiments of the series which have been of the main-plot, sub-plot type. (For the yields of these experiments see [1–4].)

TABLE 2. *Efficiency Ratios*

r = relative efficiency of lay-out for sub-plot to main-plot treatments (number of sub-plots per main plot given in parentheses).
r_m = relative efficiency of complete randomization to actual lay-out for main-plot treatments.
r_s = relative efficiency of complete randomization to actual lay-out for sub-plot treatments.

1934				1935				1936			
Site	r	r_m	r_s	*Site*	r	r_m	r_s	*Site*	r	r_m	r_s
Bahtim	16·4 (9)	6·7	0·41	Bahtim	3·5 (9)	2·9	0·83	Bahtim[1]	8·3 (6)	3·9	0·47
Gemmeiza	3·0 (9)	2·6	0·84	Tukh	3·3 (12)	2·3	0·86	Shaba[2]	3·9 (8)	3·0	0·76
				Qorashia	4·5 (12)	3·6	0·80	Ibrahimia[2]	1·2 (8)	1·2	0·98
				Sakha	1·5 (12)	1·5	0·96				
				Abu Hammad	21·9 (12)	8·9	0·40				

[1] In this experiment the nature of the treatments necessitated two successive divisions of the main plots, dates of sowing and watering-treatments being main-plot treatments, cultivation treatments being given to halves of the main plots, and nitrogen treatments to the sub-plots. The variances both for sub-plot and semi-main plot happened, however, to be almost identical, and were pooled for the purpose of the above Table. [2] After correction for salt (see p. 60).

Usually, complete randomization would have reduced the information on the sub-plot treatments to round about 85 per cent. of the actual value. Partly on the basis of such results, two of the 1936 experiments were completely randomized, each consisting of three blocks of 72 plots. The percentage standard errors for these two experiments were 8·9 and 12·0 per cent., these figures being reasonable, and comparing very favourably with the percentage sub-plot errors for other large-scale experiments of the same year (see Table 3).

It should, however, be noted that in each year there was one experiment in which it is estimated that over half the information on the sub-plot treatments would have been lost by complete randomization. At Bahtim in 1936 this is partly due to the number of main plots being fairly large (36, 6 sub-plots per main plot), but the variability of the main plots at Abu Hammad in 1935 was large, due mainly to a 'pocket' of low yield in one part of the site. In the Bahtim experiment of 1934 an examination of the distribution of plot-yields suggested that less contrast between main-plot and sub-plot variation might have been obtained if the blocks and main plots could have been more compact in shape.

There is evidently a certain risk with complete randomization (if practicable) of gaining considerably on a set of comparatively few main-plot treatments by losing somewhat heavily on the sub-plot treatments.

It would, therefore, seem advisable, before complete randomization were adopted in any experiment of this kind, to ensure as far as possible (as was done for the two actual experiments cited) that the site chosen should appear particularly suitable.

To conclude this section, a summary of the percentage standard errors obtained in the cotton experiments is given in Table 3. Further comment on them is deferred until the end of the paper.

TABLE 3. *Percentage Standard Errors*[1]

Site (1934 and 1935)	*Mean yield (k/fd)*	*% S.E.*	*Site (1936)*	*Mean yield (k/fd)*	*% S.E.*
Bahtim	6·8	7·2	Bahtim	5·7	9·6
Gemmeiza	4·4	15·1	Shaba[2]	8·4	13·6
Bahtim	5·5	7·8	Ibrahimia[2]	6·1	16·4
Tukh	7·1	8·0	Beni Suef[2]	6·6	14·2
Qorashia	7·4	8·5	Mahallet Roh	5·5	12·0
Sakha	4·9	10·0	Tukh	7·5	8·9
Abu Hammad	5·7	12·7	Shaba (small)	10·2	5·3
Abu Qir	8·2	7·0	Lishaa (small)	5·0	6·2
Biba	3·2	19·0			

[1] The sub-plot error is recorded for experiments of the main and sub-plot type.
[2] After correction for salt.

3. *The Confounding of Higher-Order Interactions*

Although, as already noted, confounding of the interactions was not often resorted to, one experiment in 1936 and two of a subsidiary group in 1935 were exceptions. At Biba, in 1935, an experiment consisted of four replications of a $3\times3\times3$ set of treatments (nitrogen, phosphate, spacing). For such a set of 27 treatments, blocks of 9 plots each can conveniently be used, since this need only involve confounding two degrees of freedom of the second-order interaction between the three factors. When four replications can be used, the lay-out is particularly attractive, since by confounding a different pair of degrees of freedom in each replication, the arrangement becomes a symmetrical one in which the entire second-order interaction is only confounded to an extent of 25 per cent., that is, we still have the equivalent of three replications for this interaction, and yet by reducing the block size from 27 to 9 have probably increased our accuracy on the whole experiment [7]. The lay-out for this experiment is shown in Fig. 1.

Again it is of interest to ask what accuracy we should have had if a different lay-out had been used; in this case if no confounding had been introduced. We may do this using Yates's method [7], neglecting the effect of confounded components of the interaction. We find that the actual lay-out used has a relative efficiency over a lay-out with no confounding of 155 per cent. for the unconfounded comparisons. Since the second-order interaction may be evaluated with the accuracy of three out of the four replications, the relative efficiency for this interaction is 116 per cent. There has thus been an estimated gain in information, even for the partially confounded effects.

For the other 1935 experiment, at Abu Qir, the third-order interaction was completely confounded in a $2\times2\times2\times2$ set of treatments (variety, spacing, nitrogen, phosphate), three replications of the 16 treatments being contained in 6 blocks of 8 (Fig. 2). Although the estimated efficiency ratio for this experiment reached only 108 per cent., these two lay-outs are both very useful examples of confounding.

For experiments of the type $3\times3\times3$ . . ., $2\times2\times2$ . . ., standard methods of confounding are available. For others like $3\times3\times2$, $3\times2\times2$, &c., methods have been worked out, though they are less common.

FIG. 1. *Lay-out for Three-Factor Experiment on Cotton at Biba, Egypt, 1935*

Spacing C, M, W; Nitrogen 0, 1, 2; Phosphate 0, 1, 2.

C N_1 P_2	C N_2	W	C N_1	M	M N_1 P_1	M N_1 P_2	C	M P_1	W N_1	M	M N_1 P_1	W N_2 P_2	C N_1	C N_2 P_1	W P_1	C N_2 P_2	C N_1 P_1
C P_1	M N_2 P_1	W N_1 P_1	M N_2 P_2	W N_1 P_2	W N_2	C N_2 P_2	W P_2	C N_1 P_1	M N_2 P_2	W N_2 P_1	W P_2	M P_1	W	C P_2	W N_2	M N_2 P_1	W N_1 P_2
M P_2	M N_1	W N_2 P_1	W P_1	C N_2 P_1	C P_2	W N_1	W N_2 P_1	M N_2	C P_1	C N_1 P_2	C N_2	M N_2	W N_1 P_1	M N_1 P_2	M P_2	C	M N_1
M N_1	W N_2	C N_1 P_2	M N_2	C N_1	W	C N_1 P_1	W N_1	M N_2 P_1	W N_2 P_1	M P_1	M N_1	M N_1 P_2	W P_2	C N_1	W N_2 P_2	C	C N_1 P_2
W P_2	W N_1 P_1	C	W N_1 P_2	M N_1 P_1	M P_2	M	W N_2 P_2	C P_2	C N_2	W N_1 P_2	C P_2	C P_1	W N_2	M N_2 P_1	M N_1 P_1	W N_1	M N_2
C N_2 P_1	M N_2 P_2	M P_1	W N_2 P_1	C P_1	C N_2 P_2	W P_1	M N_1 P_2	C N_2	M N_2 P_2	C N_1 P_1	W	W N_1 P_1	M	C N_2 P_2	C N_2 P_1	W P_1	M P_2

Other more complicated systems may have to be considered on their own merits. Thus in the 1936 experiment at Beni Suef, the treatments were the $4\times3\times2\times2$ set given by all combinations of:

Nitrogen—four levels (including zero level),
Spacing (close, medium, wide),
Phosphate,
Potash.

These 48 treatment-combinations were replicated three times, making 144 plots, but the block-size was reduced to 24 plots by partially confounding the second-order interaction $N\times P\times K$ (for details, see [6]). For this experiment the efficiency ratio for the unconfounded effects was 118 per cent., and since the interaction $N\times P\times K$ was confounded to an extent of 1/3, 79 per cent. for this interaction.

4. *The Statistical Correction for Salt-damage*

In Table 2 it was noted that the figures for the experiments at Shaba and Ibrahimia in 1936 were obtained after correction for salt. Salt-accumulation in the upper layers of the soil can be very serious in Egypt,

owing to the harm done to the crop. Such salt-accumulations are produced by inadequate drainage of sub-soil water, the salt moving upwards in the wet soil and accumulating on the surface of the ridge above the level reached by the irrigation-water. If this accumulation is severe early in the season the young cotton plants die. Patches of powdery soil, desiccated by high salt concentration where the stand of plants is greatly

FIG. 2. *Lay-out for Four-Factor Experiment on Cotton at Abu Qir, Egypt, 1935*

(Varieties A, G; Nitrogen 0, 1; Phosphate 0, 1; Spacing 1, 2 (suffix))

A_1	G_2	G_1 N	A_1 N P	A_1	G_2
G_1 N	A_2 P	G_1 P	G_2	G_1 N	A_2 P
A_1 N P	G_1 P	A_2 P	A_1	G_2 N P	A_1 N P
A_2 N	G_2 N P	G_2 N P	A_2 N	G_1 P	A_2 N
A_1 P	G_2 N	G_1 N P	G_2 P	A_1 N	A_2
G_1	A_1 N	A_1 P	A_1 N	G_2 N	A_2 N P
G_2 P	A_2 N P	G_1	A_2	G_2 P	G_1
A_2	G_1 N P	A_2 N P	G_2 N	G_1 N P	A_1 P

reduced, are a common sight in Egypt. Although the Government is digging drains in many places, the occurrence of salt is so widespread that any series of experiments, if representative, must include some experiments in which the yields of some plots are reduced by salt-damage.

In two experiments (Beni Suef and Shaba) the effect was fairly serious; in another (Ibrahimia), although this site showed considerable patchiness in some blocks, this variability was presumably due to other causes and its dependence on the accumulation of salt on the surface was apparently of less importance.

For these experiments visual estimates of the degree of saltiness of affected plots had, however, been made on a scale from 0 to 10. The scale of such salt measures was *a priori* rather arbitrary, but graphs indicated that a linear dependence of yield in this salt-measure fairly adequately summarized the variation. The graph for the Shaba experi-

ment, where the greatest number of plots was affected, is shown in Fig. 3, the yields being plotted directly against the salt index regardless of treatments or blocks.

There was no reason to suppose that the salt estimates depended on

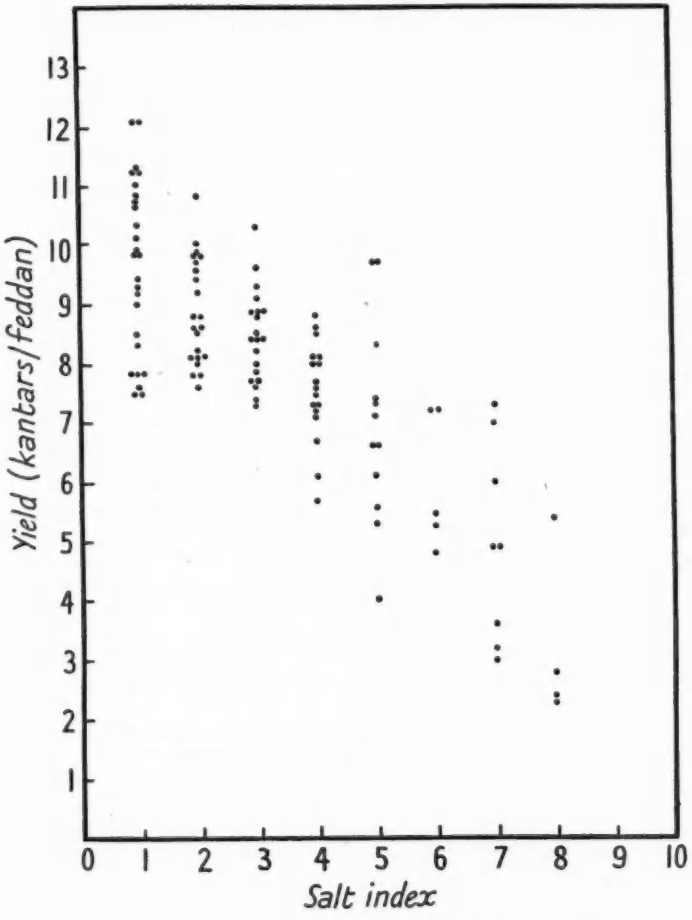

FIG. 3. Relation of yield to salt index at Shaba, 1936.

the treatments, and it was decided to correct as far as possible for the effect by means of the statistical method known as analysis of covariance [11].

For statistical details of the adjustment, which is not quite so straightforward as the orthodox analysis of variance and covariance, owing to the division of the lay-out into main and sub-plots, reference may be made

to [6]. The consequent reduction in the error-terms for the three experiments is shown in Table 4.

TABLE 4. *Estimated Error-Variances for 1936 Experiments before and after Adjustment for Salt-damage*

		Shaba	*Beni Suef*	*Ibrahimia*
Main plot (sub-plot basis)	Before adjustment	9·781	..	1·462
	After adjustment	5·127	..	1·166
Sub-plot	Before adjustment	2·866	1·409	1·048
	After adjustment	1·313	0·869	0·994

The reduction is considerable for Shaba and Beni Suef, the ratio of the variances being for Shaba (sub-plot analysis) 2·18 and for Beni Suef 1·62. For Ibrahimia (sub-plot analysis) it is comparatively unimportant, the ratio being 1·05.

Whereas the method of covariance probably gave as good an adjustment for the effect of salt as is possible, the meaning of the modified treatment-yields should be clearly realized. It would perhaps be less ambiguous to say that the yields have been equalized for salt rather than corrected for salt (their mean remaining unaltered at the actual mean level obtained over the experimental site, for all plots, salty or non-salty). Since in severe cases the salt-damage might be sufficient to check the extent to which the crop can respond to treatments, such as extra nitrogen, the experimenter might complain that such equalized yields, which will estimate, among other things, the average nitrogen response over all the plots, may not tell him everything he wants to know. An auxiliary investigation could, however, be undertaken (e.g. by estimating the yields of plots [10] which were very severely damaged) to see how far such a check on the response in the absence of salt appeared to be operating.

For the Shaba experiment the effect of the adjustment is illustrated by the nitrogen-treatment means.

TABLE 5. *Nitrogen Means, Shaba Experiment*

Yield (kantars/fed.)	N_0	N_1	N_2	N_3	*S.E.*
Before adjustment	8·24	8·13	8·36	8·88	0·28
After adjustment	8·06	8·38	8·43	8·74	0·19

Whilst the deviations from proportionality of response to rate of application of nitrogen are not significant in either case, it will be noticed that the rather anomalous drop with the first rate has been corrected by the adjustment.

An estimation of the yields of the 12 plots most affected by salt from the remaining (adjusted) plot-yields resulted in the following nitrogen means (Table 6):

TABLE 6. *Nitrogen Means, Shaba Experiment*

Yield (kantars/fed.)	N_0	N_1	N_2	N_3
(Including 12 plots estimated)	8·40	8·73	8·94	9·14

The mean level is of course raised slightly in comparison with that in Table 5; in addition, the response curve, besides happening to be even further smoothed, appears to show a slightly greater average response to nitrogen for the remaining 132 plots of the experiment.

5. *Fertility Diagrams*

The suitability of the particular lay-out adopted in any experiment can be judged to a considerable extent by reference to a fertility diagram constructed from the individual plot-yields. The construction of fertility diagrams from uniformity trials is well known, but if treatments have been superimposed, no direct estimate of the natural fertility of any plot is of course any longer available. Nevertheless, for experiments of the kind considered here, comprising a fairly large number of plots, quite a good estimate can be expected for the natural yield of any area by adjusting the plot-yields for the estimated treatment-differences.[1] To eliminate discrepancies between neighbouring plots, due to error in the estimate of treatment-effects, the yields for adjacent plots were averaged, though this would sometimes tend to smooth discrepancies due to real patchiness. Further, it is assumed that the treatment-effects are reasonably constant over the whole site. For lay-outs of the main-plot, sub-plot, type it must be remembered that any error in the correction for the effect of a main-plot treatment will be reflected in the adjusted yields of all the sub-plots of the same main plot.

Provided these limitations are noted, the diagrams are of considerable interest not only for their immediate aid in explaining the efficiency of the lay-outs, but in their general indications of the nature of the fertility-variation in the Egyptian experimental sites considered. Three representative diagrams are given here. The first (Fig. 4) is for the 1934 Bahtim experiment, the second (Fig. 5) for the 1936 Mahallet Roh experiment, one of the two 1936 experiments in which complete randomization of the whole 72 plots per block was adopted, and the third (Fig. 6) for the 1936 Shaba experiment, one of the experiments which suffered from salt-damage in that year.

For the experiment at Mahallet Roh there is an obvious fertility-gradient from one end to the other of the site, which was successfully eliminated as 'blocks', but apart from this the site appears reasonably uniform, this being consistent with the satisfactory nature, in this instance, of the kind of lay-out adopted. For the other completely ran-

[1] The information these adjusted yields provide on the fertility variation of the site is not as a rule further utilized. Papadakis [12] has, however, recently suggested that the error of experiments can often be reduced by means of the observed covariance between the adjusted plot-yields and similar yields from neighbouring plots. It is intended that a critical examination of the theoretical validity and practical usefulness of this method be published in due course; but at this stage it seems worth pointing out that if any complex field experiment were to be completely randomized within blocks, as in the Mahallet Roh and Tukh lay-outs, the risk of losing information could tend to be partly offset by the knowledge that such apparently lost information might, if necessary, be recoverable by further analysis.

domized experiment at Tukh, the site was even more uniform, and gave a smaller standard error and no significant block-differences.

For the Shaba experiment, in which the yields are given uncorrected

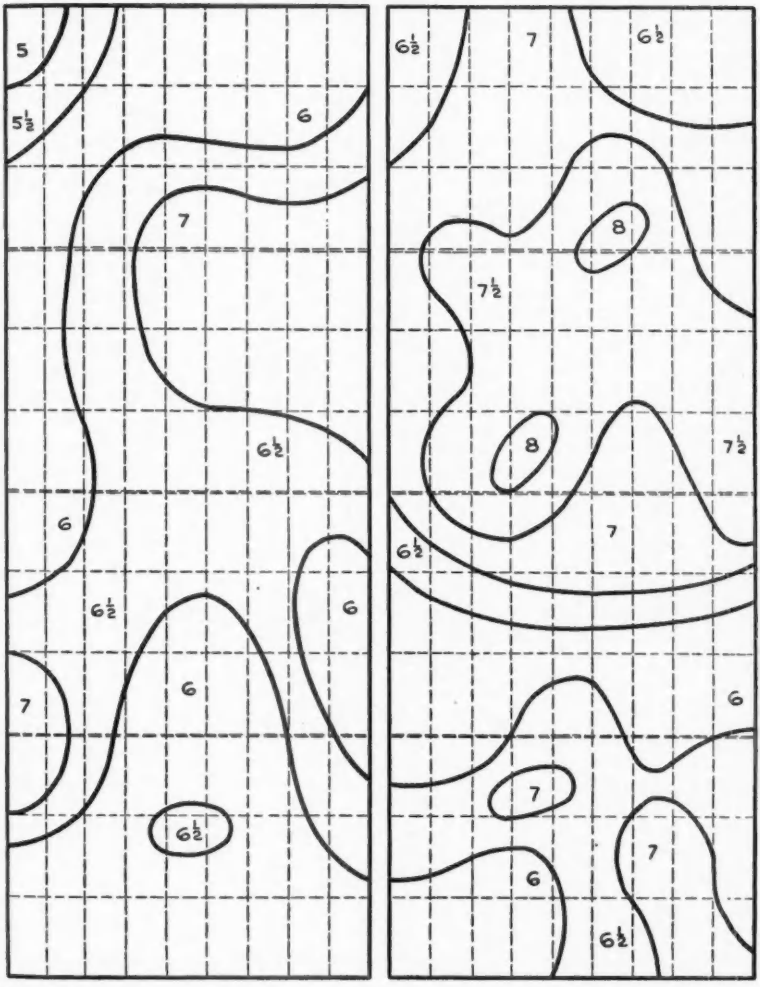

FIG. 4. Variation in natural fertility at Bahtim, 1934 (yield in kantars per feddan).

for salt-damage, the chief source of variation is patchiness due to this cause, the whole site appearing very heterogeneous, and showing a range in yield from 4 to 12 kantars per feddan.

On the whole, these diagrams and those for the remaining experi-

ments, although often showing steady gradients sweeping across the site, tended to agree in indicating additional variations in fertility of a much more chaotic character, which could hardly be forecast. Blocks arranged as compactly as possible seem the safest way of trying to insure against variation of this kind contributing excessively to the experimental error.

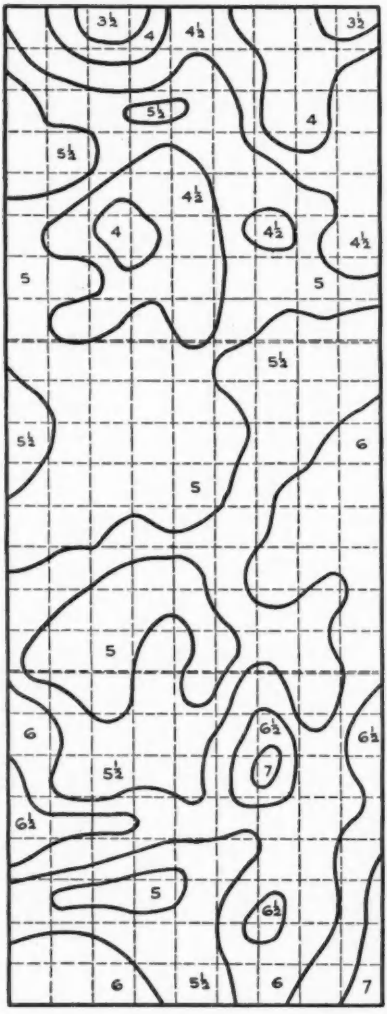

FIG. 5. Variation in natural fertility at Mahallet Roh, 1936 (yield in kantars per feddan).

Inspection of Table 3 suggests that, apart from some exceptions, the standard errors of the experiments were reasonably satisfactory. Practical conditions, such as the field work entailed, or the necessity for keeping cultural or varietal treatments in main plots, impose certain limitations on the choice of lay-out, but one of the chief causes of loss of accuracy, where it has occurred, has been patchiness of some form or another. This effect is necessarily serious, since no arrangement of the plots is likely to be able to counteract it. Even for the salt experiments, the adjustment used still tended to leave higher standard errors than the average. The choice of a site free from this kind of variability is, where possible, a useful beginning to the carrying-out of an accurate experiment, and conversely, a patchy site may already imply an experiment's partial failure. This can be seen to some extent by some rather anomalous results of the Ibrahimia experiment, in which both the first-order interaction between spacing and phosphate and the highest-order interaction between all the factors were apparently significant. On further examination the site was found not only to be patchy, but the patchiness to be very different in the three blocks, one block being very uniform and one very variable. This difference was sufficiently marked to render suspect the validity of the orthodox analysis of the results, and hence the real significance of these interaction-terms, especially as the chief contribution to these terms came from the most variable block.

Summary and Conclusion

The experimental and statistical technique used in a series of complex cotton experiments carried out in Egypt during 1934–6 is discussed in relation both to the objects of the research programme and to the particular conditions determining field experimentation on the cotton crop in Egypt.

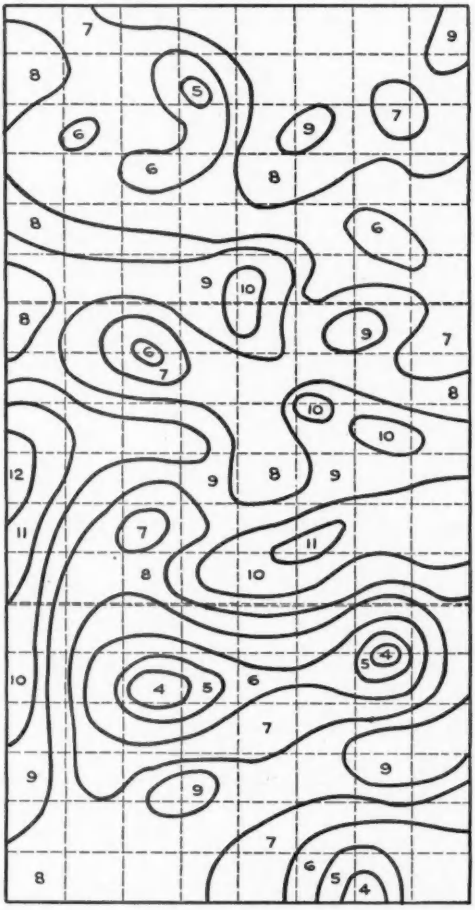

FIG. 6. Variation in natural fertility at Shaba, 1936 (yield in kantars per feddan).

Statistical aspects of the results considered include figures on the relative accuracy of main and sub-plot, or of partially confounded, to completely randomized, lay-outs; and the correction for damage due to salt-accumulation in the upper layers of the soil for three of the 1936

experiments. The variation in fertility throughout the site in three representative experiments is illustrated.

The exact type of lay-out decided on is necessarily a problem demanding some deliberation, depending both on practical and theoretical considerations. No lay-out, however, will eliminate extreme patchiness, and the need for care in the choice of an experimental site is, of course, not to be neglected.

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THE CHEMICAL COMPOSITION OF THE GRAIN AND STRAW OF VARIETIES OF OATS BRED AT THE WELSH PLANT BREEDING STATION: COMPARISON WITH SOME OLDER VARIETIES

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Introduction.—The oat crop is by far the most important cereal grown in Wales, mainly owing to the climate. Investigations have shown that the crop needs cool humid conditions in its later life-period, and that high temperatures, particularly when accompanied by low rainfall in the later stages of ripening, may seriously affect grain yields [1]. The importance of the crop in Wales is shown by the figures in Table 1, which have been

TABLE 1. *Areas under Cereal Crops in England and in Wales*

	Total arable acreage	*Wheat* %	*Barley* %	*Oats* %
England, excluding Monmouth . .	9,404,489	15·1	11·1	16·9
Wales, including Monmouth . .	651,211	3·3	6·6	26·5

calculated from official returns [2], and also by the circumstance that the greater part of the mixed corn grown for fodder consists mainly of oats. Owing to the economic importance of the crop in Wales more attention is paid to its improvement than to that of any other cereal, and the breeding of new varieties is one of the chief activities of the Welsh Plant Breeding Station. Among the most important factors sought in improved varieties are straw-stiffness, early maturity, yield including the proportion of head corn, size, shape and quality of grain, and general resistance to disease [3]. For many years investigations with old and new varieties have been conducted by this Station in various parts of Cardiganshire, Montgomeryshire, and Merionethshire, and samples of grain and straw obtained from these counties in 1932, 1933, and 1934 provided the material for studying the chemical composition of oats grown under the conditions prevailing in Wales. The main object of this paper is to compare the chemical composition of the grain and straw of old and new varieties and to show how it varies under certain conditions.

The Chemical Composition of Oat Grain

For purposes of comparison the head and tail corn were separated by means of a standard grading-machine, and the head corn alone was analysed after grinding it to pass through the $\frac{1}{64}$-inch sieve of a Christy and Norris mill. The moisture-content of the samples varied widely so that the percentages of chemical constituents are expressed on a dry-matter basis.

One of the first facts which emerged was the remarkable similarity in chemical composition of the grain of the old and new varieties of *Avena sativa*, grown under similar conditions. This is illustrated in Table 2, from which it is seen that more than one selection from the same cross has been studied.

TABLE 2. *Chemical Analysis of the Dry Matter in the Grain of Old and New Oat Varieties (per cent.)*

	Victory	*Marvellous*	*Record*	*Golden Rain II*	*Star*	*Victory × Red Algerian 289*	*Record × Radnorshire Sprig 275*	*Record × Radnorshire Sprig 274*	*Golden Rain × Radnorshire Sprig 266*	*Golden Rain × Red Algerian 258*	*Golden Rain × Yielder 254*
Crude protein .	9·3	9·6	9·5	9·6	9·7	9·6	10·1	9·7	9·8	10·4	11·0
True protein .	8·9	9·1	8·8	9·0	8·8	9·3	9·7	9·0	9·5	9·8	10·3
Ether-extract .	5·40	5·86	6·40	6·01	5·52	5·82	5·72	5·78	5·86	5·94	5·90
Crude fibre .	11·9	12·0	12·7	11·7	9·8	11·2	13·2	10·7	11·5	10·5	10·7
Soluble carbohydrates . .	69·9	69·4	68·5	69·2	71·8	70·3	68·0	71·1	69·5	69·8	69·6
Ash . . .	3·46	3·13	2·91	3·17	3·19	2·98	2·94	2·76	3·34	3·26	2·85
Silica . .	1·38	1·10	1·04	1·31	1·27	1·11	0·97	0·96	1·28	1·30	0·92
Silica-free ash .	2·18	2·02	1·87	1·86	1·92	1·87	1·97	1·80	2·06	1·96	1·93
Phosphoric acid (P_2O_5) .	0·84	0·80	0·82	0·83	0·83	0·79	0·85	0·76	0·85	0·78	0·65
Lime (CaO) .	0·13	0·11	0·12	0·13	0·14	0·12	0·15	0·13	0·15	0·14	0·12
Potash (K_2O) .	0·45	0·71	0·66	0·58	0·70	0·73	0·72	0·63	0·70	0·66	0·74
Chlorine (Cl) .	0·09	0·17	0·10	0·13	0·09	0·11	0·15	0·07	..	0·10	0·12

With few exceptions the percentages of chemical constituents, e.g. protein and ether-extract, are very similar, and the new varieties compare very favourably with the older ones in this respect. The differences in the percentages of ash are largely accounted for by variation in the silica-content, for the differences in the percentage of silica-free ash in the above varieties are but small. This is also true of the phosphoric acid and lime, but the potash and chlorine appear to be subject to greater variation.

Although the data in Table 2 show very slight differences in chemical composition between the old and new varieties of *Avena sativa*, evidence was obtained that considerable variation occurs in the composition of the grain of different species of oats, and that this is influenced considerably by local and seasonal conditions.

Influence of locality.—Table 3 gives the percentages of chemical constituents subject to greatest variation in seven varieties grown on three Cardiganshire farms. The varieties within the species given in Table 3 were grown on six different farms in Cardiganshire and Merionethshire in 1933. The Ceirch Llwyd S. 78 is a pure-line selection from *Avena strigosa*, the little grey oat of Wales, also known as Ceirch Llwyd, Ceirch Teify, and Blewgeirch [4]. Experience has shown that it is very hardy and superior to any of the varieties of *Avena sativa* on poor land. It ripens under conditions of high rainfall and often recovers after lodging. The awned grain makes it difficult to thresh and winnow, but this dis-

advantage is not serious when the grain and straw are chaffed together for feeding purposes. Owing to the grain of Ceirch Llwyd being rather small, attempts were made to combine the advantages of *Avena strigosa* with grain of improved quality, and eventually the variety Ceirch Llwyd Cwta was produced by crossing the former with *Avena brevis*. This new variety has grain with a very short awn, and recent trials have shown that it is very suitable for growth under Welsh conditions [5].

TABLE 3. *Chemical Composition of the Grain of* Avena sativa, Avena strigosa, *and* Avena strigosa × Avena brevis

		Varieties of Avena sativa					*Ceirch Llwyd S. 78* (Avena strigosa)	*Ceirch Llwyd Cwta* (A. strigosa × A. brevis)
		Golden Rain II	*Victory*	*Engelbrekt*	*Victory* × *Red Algerian S. 84*	*Record* × *Radnorshire Sprig 274*		
Crude protein	1[1]	11·9	11·8	11·8	12·6	11·7	12·7	13·1
	2	12·5	..	11·3	12·9	12·1	13·2	14·1
	3	11·9	..	10·9	11·5	11·5	12·8	13·9
Ether-extract	1	6·08	5·39	5·83	5·56	5·43	6·48	6·93
	2	5·49	..	5·80	5·70	5·25	6·39	6·33
	3	5·98	..	6·60	5·90	5·52	6·65	6·39
Silica-free ash	1	1·81	1·93	1·87	2·00	1·77	2·23	2·16
	2	1·89	..	2·04	1·96	1·78	2·26	2·32
	3	1·80	..	1·68	1·92	1·79	2·34	2·40
Phosphoric acid (P_2O_5)	1	0·91	0·92	0·76	0·94	0·89	1·06	1·09
	2	0·81	..	0·66	0·79	0·81	0·89	0·78
	3	0·86	..	0·77	0·80	0·84	1·01	1·05
Lime (CaO)	1	0·14	0·15	0·14	0·16	0·14	0·25	0·20
	2	0·11	..	0·13	0·12	0·11	0·17	0·15
	3	0·10	..	0·12	0·11	0·11	0·17	0·17

[1] The figures 1, 2, and 3 denote the three centres Nantcellan, Penuwch Fach, and Pwllpeiran, situated 150, 550, and 950 ft. above sea-level, respectively.

Whilst confirming the observation made previously regarding the similarity in chemical composition of the varieties of *Avena sativa*, the outstanding feature of these results is that Ceirch Llwyd and Ceirch Llwyd Cwta are in almost every case richer in protein, ether-extract, silica-free ash, phosphoric acid, and lime than the varieties of *Avena sativa*. It is also evident that these two varieties resemble one another in chemical composition.

Similar conclusions were derived from a study of the same varieties from three Merionethshire farms where Scotch Potato was also grown. When this variety, well known for its high-quality grain, was compared with Ceirch Llwyd and Ceirch Llwyd Cwta, it was found to be slightly

richer in protein but poorer in ash-constituents, particularly lime, and it had a similar oil-content. The latter varieties are typical straw-producers, which do well in northern districts of heavy rainfall. It has been pointed out [6] that in such districts old-established varieties of *Avena sativa*, such as Scotch Potato and Sandy, are still popular, being characterized by a high yield of straw and grain of good quality. It seems probable, therefore, that in contrast to the heavy grain-yielding varieties, the grain of the straw-producers is richer in protein, oil, and certain ash-constituents.

Although there is little well-marked variation in the composition of the oat grain at the centres referred to in Table 3, the results presented in Table 4 show that local conditions are important from this point of view.

TABLE 4. *Variation in Chemical Composition of Oat Grain with Locality*

Centre	*Variety*	*Crude protein*	*Ether-extract*	*Silica-free ash*	*Phosphoric acid* (P_2O_5)	*Lime* (CaO)
Nantcellan, 150 ft. above sea-level	Golden Rain II	11·9	6·08	1·81	0·91	0·14
	Engelbrekt	11·8	5·83	1·87	0·76	0·14
	Ceirch Llwyd	12·7	6·48	2·23	1·06	0·24
	Ceirch Llwyd Cwta	13·1	6·93	2·16	1·09	0·20
Berthllwyd, 300 ft. above sea-level	Golden Rain II	13·7	5·56	1·89	0·89	0·11
	Engelbrekt	11·9	5·46	1·60	0·81	0·12
	Ceirch Llwyd	14·0	7·16	2·08	1·05	0·14
	Ceirch Llwyd Cwta	14·6	6·95	2·13	1·07	0·14
Hafod Oer, 750 ft. above sea-level	Golden Rain II	15·7	4·81	1·84	0·97	0·12
	Engelbrekt	12·8	4·61	1·77	0·87	0·12
	Ceirch Llwyd	14·5	6·65	2·07	1·43	0·18
	Ceirch Llwyd Cwta	14·8	6·50	2·03	1·04	0·16

Table 4, giving the chemical composition of the grain of four varieties grown at different centres in 1934, shows the variation which occurs in different localities, and also confirms the conclusions arrived at above regarding the superiority of the varieties Ceirch Llwyd and Ceirch Llwyd Cwta.

The grain grown at Hafod Oer, situated in a cold late district, is richer in protein and, except in one case, poorer in ether-extract than that grown near sea-level at Nantcellan. The grain obtained from Berthllwyd is also relatively rich in protein; and there is considerable variation in the percentages of mineral constituents, particularly lime and chlorine, in the varieties grown at different centres. At Nantcellan there is usually no difficulty in harvesting the crop, whereas at Hafod Oer and Berthllwyd, situated in much later districts, it is often harvested in an immature condition. Consequently, in these districts the transference of nutrients from the straw to the grain is incomplete and the latter is rich in protein, this being a characteristic of poorly filled grain [7]. At the same time the straw is relatively rich in crude protein and has a much higher nutritive value than mature straw; this is shown in a very striking manner by the figures in Table 5, the straw from Hafod Oer having an exceptionally high protein-content when compared with the mature straw from the other centres.

In its protein-content the straw from Hafod Oer more closely resembles hay than straw, and it also contains less fibre and more phosphoric acid and lime than the mature straw from Nantcellan. This superiority in chemical composition of straw from a late district is important when it is realized that the practice of cutting the oat crop in an immature condition for feeding whole is common in the more hilly districts of Wales.

Further evidence of the effect of locality on the chemical composition of the crop was obtained from a study of oats grown at different centres in Merionethshire and Montgomeryshire.

TABLE 5. *Composition of Mature and Immature Straw*

Percentage	*Golden Rain*		*Engelbrekt*		*Ceirch Llwyd*		*Ceirch Llwyd Cwta*	
	1	2	1	2	1	2	1	2
Crude protein . .	3·0	8·3	3·2	7·6	2·3	7·4	2·5	6·6
Crude fibre . .	41·3	34·5	38·4	36·1	44·8	38·5	43·7	40·0
Phosphoric acid (P_2O_5) .	0·28	0·36	0·27	0·37	0·18	0·27	0·26	0·39
Lime (CaO) . .	0·42	0·50	0·50	0·53	0·45	0·43	0·39	0·51

(1) Mature straw grown at Nantcellan.
(2) Immature straw grown at Hafod Oer.

Influence of season.—During the period of this investigation the weather varied considerably. Table 6 gives the annual rainfall at the Welsh Plant Breeding Station for the period 1925–35.

TABLE 6. *Annual Rainfall at Aberystwyth (inches)*

Year	*Rainfall*	*Year*	*Rainfall*
1925	40·54	1931	45·50
1926	38·81	1932	38·61
1927	49·71	1933	26·96
1928	51·21	1934	39·68
1929	44·79	1935	51·22
1930	46·93		

Average 43·09 in.

The table shows that the annual rainfall in 1933 was very much lower than that in 1932, 1934, or in the average of the eleven years 1925–35; further, the rainfall for 1933 was approximately 12 in. less than that in 1926 and 1932, which had the next lowest rainfall.

From the point of view of plant-growth the rainfall during the period March–August is probably more important than the annual rainfall. The figures for monthly rainfall show that for this period it was only 10·38 in. in 1933, compared with 16·52 and 18·03 in. in 1932 and 1934, respectively. Russel and Bishop have shown that rainfall is the most important weather factor affecting the nitrogen-content of barley, and that the nitrogen-content and other properties connected with it are chiefly determined in April, May, and June, being little affected by the weather during the time of ripening in July and August [8]. The rainfall for April, May, and June was 9·54 and 9·74 in. in 1932 and 1934,

respectively, and only 4·55 in. in 1933. That year being exceptionally dry, any effect which seasonal influences might have on the chemical composition of the oat crop would be particularly pronounced. Evidence of this is presented in Table 7, where the protein-content of the grain of *Avena strigosa* and *Avena strigosa* × *Avena brevis*, grown at the Welsh Plant Breeding Station, Frongoch, in 1933, is compared with averages for the much wetter years 1934 and 1935.

TABLE 7. *Comparison of Protein-content in a Dry and in Two Wet Years*

	Percentage crude protein			
	1933		*1934*	*1935*
Variety	*Grain*	*Straw*	*Grain*	*Grain*
A. strigosa (Ceirch Llwyd) . . .	15·9	5·1	13·3	11·7
A. strigosa × *A. brevis* (Ceirch Llwyd Cwta) .	15·6	6·6	13·4	12·8

In addition to this particular strain of *A. strigosa* × *A. brevis*, four closely related strains were grown in 1933 and were consistently rich in crude protein, the percentages in the grain and straw being 16·2, 16·5, 16·4, 16·0, and 5·8, 6·6, 5·4, and 5·0, respectively. The exceptionally high protein-content during 1933 is attributed to the very dry weather which greatly hastened maturity, with the result that transference of nutrients to the grain was incomplete and the latter poorly filled. The high protein-content of the straw supports this contention. In spite of the incomplete transference of nitrogen to the grain, the latter was exceptionally rich in protein, probably because the carbohydrates formed in the leaves were still less completely transferred to the grain. Knowles and Watkin have shown that the dry matter entering the oat ear gets richer in nitrogen-free organic matter and poorer in constituents obtained from the soil as the plant matures [9].

Another reason for the pronounced effect of seasonal influences in 1933 is that the soil on which the crop was grown is very light and shallow, and suffers badly during a drought. Investigations on barley [8] showed that variations in the nitrogen-content of the grain due to season are greatest on sandy soils and least pronounced on loams and heavy soil.

Table 8 gives the mechanical analysis of the soil on which the crop under discussion was grown, together with that of Gilwern field, Nant-

TABLE 8. *Mechanical Analysis of Soils at Nantcellan and Frongoch* (*Percentages*)

	Stones	*Fine gravel*	*Coarse sand*	*Fine sand*	*Silt*	*Fine silt*	*Clay*	*Moisture*	*Loss on ignition*
Gilwern Field, Nantcellan	9·5	1·6	3·0	8·0	14·6	36·2	19·6	4·0	11·4
Bank Field, Frongoch .	32·9	12·7	8·7	8·4	10·6	29·5	11·6	3·8	15·1

cellan [10, 11]. The marked differences in physical texture provide a probable explanation for the magnitude of the seasonal effect at Frongoch, and the absence of any appreciable effect at the College Farm, Nantcellan, situated in a neighbouring locality.

It may be concluded that a period of drought, particularly when its effects are accentuated by other factors, such as the light nature of the soil, tends to hasten the maturing of the oat crop, in consequence of which transference of nutrients to the grain is incomplete and both grain and straw are exceptionally rich in crude protein.

The results already presented indicate that whereas the grain of the varieties of *Avena sativa* examined varies but little in chemical composition, there are considerable differences in the composition of the grain of different species of oats. It is, therefore, interesting to see whether this also applies to the straw.

Chemical Composition of Oat Straw

In a previous publication [12] it was shown that strong straws were richer in certain ash-constituents and poorer in fibre than weaker straws, the chemical analysis being made after removal of the leaves. The data did not, therefore, represent the composition of straw as fed to stock, whereas in the present investigation the material was examined with this end in view, and the figures in Table 9 are typical of the results obtained.

TABLE 9. *Percentage Composition of the Straw of Different Oat Varieties*

Variety	*Strength of straw*	*Crude protein*	*Ether-extract*	*Crude fibre*	*Soluble carbohydrates*	*Silica-free ash*	*Phosphoric acid* (P_2O_5)	*Lime* (CaO)	*Potash* (K_2O)	*Chlorine* (Cl)
(Grey Winter × Kyko × Grey Winter × Bountiful)	Very strong	2·7	2·00	45·0	44·9	3·66	0·16	0·47	1·08	0·87
Victory × Red Algerian . .	Strong	3·4	2·50	41·7	47·0	4·10	0·16	0·48	1·13	0·90
Record . .	Strong	2·3	2·08	45·1	43·5	3·52	0·25	0·41	1·40	0·81
Marvellous . .	Strong	2·5	2·02	42·2	46·6	3·17	0·21	0·46	1·47	0·74
Victory . .	Medium	2·4	1·60	44·5	44·8	4·16	0·18	0·48	1·50	1·06
Golden Rain .	Medium	2·1	2·00	47·4	42·2	3·94	0·29	0·40	1·71	0·87
Scotch Potato .	Weak	3·1	2·48	42·5	47·7	2·90	0·16	0·44	1·19	0·75
Ceirch Llwyd .	Weak	2·7	2·28	45·9	44·9	3·12	0·14	0·40	0·98	0·69
Ceirch Llwyd Cwta	Weak	3·0	2·15	44·0	46·0	3·29	0·23	0·40	1·02	0·88

The figures point to two important conclusions. In the first place they show that the varieties having strong straw compare favourably in chemical composition with those having weak straw. Secondly, there appears to be no significant difference in the composition of the varieties of *Avena sativa* when compared with *Avena strigosa* (Ceirch Llwyd) and *Avena strigosa* × *Avena brevis*. Indeed, these results, together with a large number of others, lead to the conclusion that there is little difference in the composition of the mature straw of different varieties of oats when grown under similar conditions. It is therefore difficult to understand the predilection which farmers have for particular varieties; in Wales, for example, Scotch Potato and Radnorshire Sprig are generally regarded as having straw of superior feeding-value. This is probably a question of appearance and palatability, for the weaker straws are generally more slender and bear a closer resemblance to hay than the

strong coarser varieties. The evidence obtained from chemical analysis is probably insufficient to establish the relative merits of different varieties from this point of view, for the straw of one variety may conceivably be superior to that of another in its content of nutrients, but be less palatable and digestible and therefore of less value as fodder.

In addition to the chemical constituents dealt with in the previous sections the true protein was determined by Stutzer's method, and the pepsin–HCl soluble protein by the method of Wedemeyer. Some interesting data were obtained for the straw of high protein-content, already referred to in Tables 5 and 7.

In Table 10 the percentage crude fibre, crude protein, true protein, amides, and the percentage digestibility of the crude protein, as determined by Wedemeyer's method, are given.

TABLE 10. *Chemical Analysis and Digestibility of Crude Protein in Oat Straws (percentages)*

Crude fibre	*Crude protein*	*True protein*	*Amides*	*Digestibility of crude protein*
44	2·2	2·0	0·2	53
43	2·8	2·3	0·5	64
37	7·7	6·7	1·0	65
40	5·9	3·8	2·1	76

The figures are average results obtained from the analysis of a large number of samples. They show quite clearly that the digestibility (HCl-pepsin solubility) of the crude protein increases with the amide-content of the straw, but no evidence was obtained to show that the protein of straw of high fibre-content was less digestible than that of straw containing less fibre. Assuming that Wedemeyer's 'in vitro' method gives a relative measure of protein-digestibility, it appears that in addition to the higher percentage of protein present in straw harvested in an immature condition, e.g. in the more hilly districts of Wales, this constituent is also much more digestible and therefore of greater value as animal food.

The pepsin–HCl soluble protein in oat grain was also determined and appeared to decrease slightly as the percentage of fibre increased. This variation is considered to be of no practical importance, for feeding trials with poultry have shown that although the digestibility of the organic matter and the nitrogen-free extract are depressed by the fibre present in oats, this is not true of the protein and fat [13].

As already mentioned, a large number of samples of oat grain and straw were analysed during this investigation. In conclusion, it is appropriate to present the average figures obtained. The total number of samples of grain and straw analysed was 93 and 140, respectively, but of these some showed abnormally high percentages of certain constituents; for example, both straw and grain grown at the Welsh Plant Breeding Station, Frongoch, in 1933 (see Table 6) were exceptionally rich in crude protein. The average figures given in Table 11 do not include such figures, but represent the composition of the crop as grown under more normal conditions.

The figures show that the oat grain is characterized by its high content of soluble carbohydrates and other organic constituents, of which the protein and oil are the more important. The nitrogen is present mainly in the form of true protein, and about 93 per cent. of the crude protein is soluble in pepsin–HCl solution. The ash-content of the grain is low and consists largely of silica, phosphoric acid, and potash, with much smaller amounts of lime and chlorine. Oat straw, on the other hand, consists mainly of crude fibre and soluble carbohydrates, which together comprise about 90 per cent. of the dry matter. The straw is poor in nitrogen

TABLE II. *Average Percentage Chemical Composition of the Dry Matter of the Oat Grain and Straw Analysed in this Investigation*

	Crude protein	*True protein*	*Percent. digestibility of the crude protein*	*Ether-extract*	*Crude fibre*	*Soluble carbohydrates*	*Ash*	*Silica*	*Silica-free ash*	*Phosphoric acid* (P_2O_5)	*Lime* (CaO)	*Potash* (K_2O)	*Chlorine* (Cl)
Grain . .	11·8	10·1	92·7	6·13	11·4	67·5	3·10	1·14	1·96	0·87	0·13	0·61	0·09
Number of samples .	80	44	60	80	80	80	80	80	80	80	80	80	80
Straw . .	2·7	2·0	57·5	2·29	43·0	46·0	5·72	1·90	3·82	0·22	0·45	1·40	0·83
Number of samples .	80	40	40	90	80	80	90	90	90	90	100	100	100

and oil, the former being much less soluble in pepsin–HCl solution than that of the grain. Compared with the grain, oat straw is richer in ash and silica-free ash, and whereas the inorganic portion of the grain consists mainly of phosphoric acid and potash, the ash of oat straw contains a much higher percentage of lime, potash, and chlorine, but a very much lower percentage of phosphoric acid.

Summary and Conclusions

This paper deals with the chemical composition of the grain and straw of new varieties of oats bred at the Welsh Plant Breeding Station in comparison with that of some older varieties.

The new varieties compared very favourably in composition with the older standard varieties. Although there were only small differences in the composition of the grain of varieties of *Avena sativa* when grown under similar conditions, selected strains of *Avena strigosa* and *Avena strigosa* × *Avena brevis* were richer in protein, oil, phosphoric acid, and lime than the former. Variation occurred in the composition of oats grown at different centres. When grown in a late district the grain was poorly filled, owing to incomplete transference of nutrients from the straw; both grain and straw were richer in crude protein than where the crop was harvested when fully mature. Straw and grain containing abnormally high percentages of protein were also obtained when the drought of 1933 was accentuated by the light nature of the soil.

The mature straw of different varieties did not vary appreciably in composition, and varieties bred for strength of straw compared favourably in this respect with weak-strawed varieties.

Little relationship was found between fibre-content and digestibility of the crude protein, determined by Wedemeyer's method, but the digestibility was much higher in the straw of high protein and amide-content than in straw containing lower percentages of these constituents.

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DICALCIUM PHOSPHATE AND STEAMED BONE-FLOUR AS SUPPLEMENTS FOR A PHOSPHORUS-DEFICIENT RATION

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ALTHOUGH the question of a deficiency in the phosphorus-content of the rations of farm stock is not as important in Great Britain as it is in some parts of the world, in view of the somewhat conflicting statements occurring in the literature with regard to the relative availability to animals of the phosphorus in different combinations it appeared of interest to study this problem somewhat further.

Du Toit and Green [1] found that precipitated dicalcium phosphate, when fed as a supplement to young oxen grazing on a phosphorus-deficient pasture, was three times as effective, weight for weight, as bone-meal and, at the prices then current, was very much cheaper. Huffman *et al.* [2] when working on the phosphorus-requirements of dairy cattle were unable to confirm this finding. They found that, in the case of one cow, when a supplement of 98 gm. of bone-meal was replaced by 33 gm. of dicalcium phosphate, the level of blood inorganic P dropped from 4·7 to 2·6 mg. per 100 ml., but rose again to normal when the supplement was changed back to 78 gm. of bone-meal.

Maynard and Rottensten [3], from a balance study with cows, report that bone-meal and dicalcium phosphate were utilized equally well when fed at the rate of 1·5 gm. per kg. of milk secreted. These authors [4] also carried out paired feeding experiments with newly weaned rats over a period of 35 days at three different levels of phosphorus-intake, the two above-mentioned supplements being used at each level. The relative effect was measured by determining the percentage and total weight of ash in the dry fat-free bones of the hind leg. In a further experiment the same supplements were used with female rats carried through from weaning to the end of their first lactation, and any effect was measured by the weights of the rats at 4 months of age, the number of young born, the weight of young reared, the percentage of ash in, and the weight of, the dry fat-free femur of the does, and the inorganic P level of their plasma. The authors consider that, whilst the results generally favour the secondary as compared with the tertiary phosphate, they do not furnish definite proof, owing to the small differences involved and the variability of the individual data. It must be noted, however, that their diets were supplemented with calcium carbonate to equalize the calcium-intake, and this may have affected their results.

Newlander *et al.* [5] carried out balance experiments with two dairy cows, to each of which commercial dicalcium phosphate and steamed bone-flour were fed in successive lactations. Each supplement was fed at the rate of 100 gm. per day. They claim that the effects were practically equal, as determined by calcium and phosphorus balances.

In the Ninth Annual Report of the C.S.I.R., Australia [6], brief refer-

ence is made to an experiment in progress with groups of pen-fed lambs, and it is stated: 'After seven months, there is no significant difference between the groups receiving bone-meal, dicalcic phosphate, or Christmas Island rock phosphate.'

In view of the above results, it was decided to carry out balance experiments on sheep with the object of determining the actual utilization of the phosphorus in the forms of dicalcium phosphate and steamed bone-flour, when used as supplements to a phosphorus-deficient ration, and also their effects on the level of the blood inorganic phosphorus of the experimental animals.

Experimental

One of the chief difficulties in carrying out work of this nature was to devise a suitable ration that would be deficient in phosphorus, and it was finally decided to use a ration consisting of oat straw (chopped), dried beet-pulp, starch, and blood-meal, which had a P_2O_5-content of about 0·14 per cent. The experiment was divided into four periods, as follows:

Period I.	29.xi.35–21.i.36.	Basal ration.
Period II.	22.i.36–21.iv.36.	Basal ration plus dicalcium phosphate.
Period III.	22.iv.36–27.vii.36.	Basal ration.
Period IV.	27.vii.36–1.x.36.	Basal ration plus steamed bone-flour.

Four Oxford cross wethers were used for the experiment. On two of these (Nos. 54 and 61) the nitrogen, calcium, and phosphorus balances were determined, once each during Periods I, III, and IV, and twice during Period II. The other two animals were kept in reserve. Blood samples were taken from time to time on all four animals, and determinations were made of blood inorganic P, serum Ca, Mg, inorganic P, and phosphatase. The blood data, which are shown in Table 1, were used to determine when the animals were showing marked signs of phosphorus-deficiency, or alternatively, had responded to the use of the phosphatic supplement, and thus were in a condition suitable for determining the nitrogen, calcium, and phosphorus balances.

During Period I the animals went off in condition very markedly, and their appetite dropped considerably; this is reflected by the composition of the blood samples drawn on 21.xii.35 and 16.i.36. As soon as the dicalcium phosphate was introduced the appetites of the animals, as well as their general condition and blood picture, improved very rapidly. This response to the phosphatic supplement is clearly indicated by the figures for the blood samples drawn on 24.ii.36 and 22.iv.36. The dicalcium phosphate was taken out of the ration on the latter date, and, although there was no marked drop in appetite, there was a marked and rapid alteration in the blood picture, and by 27.v.36 the figures for the sample taken on that day indicated that the animals were suffering from a marked phosphorus-deficiency, as shown by low values for inorganic P in blood and serum and raised values for calcium and phosphatase in the

serum. The animals remained in this condition until after 27.vii.36, on which date steamed bone-flour was introduced into the ration, when there was a very rapid response, as shown by the raised values for blood and serum inorganic P and the lowered values for serum calcium and phosphatase obtained on 21.viii.36.

TABLE 1. *Analytical Data of Blood Samples*

	Period I		Period II		Period III			Period IV	
Dates of Sampling	21.xii.35	16.i.36	24.ii.36	22.iv.36	27.v.36	6.vi.36	11.vii.36	21.viii.36	28.ix.36
Sheep No. 54									
Blood: Inorganic P	2·36	..	6·96	..	2·50	2·56	..	6·78	7·69
Serum: Inorganic P	2·96	4·40	8·16	8·90	2·94	3·08	2·48	7·56	8·76
„ Ca	13·0	13·3	11·0	12·3	13·9	12·9	14·3	10·3	10·6
„ Mg	2·6	..	..	..	2·4	2·5	2·9	2·7	2·7
„ Phosphatase	14·4	13·1	10·0	7·9	12·9	14·3	..	7·7	6·0
Sheep No. 60									
Blood: Inorganic P	2·66	..	8·89	..	2·42	2·40	..	9·73	5·10
Serum: Inorganic P	3·48	3·16	11·44	10·12	2·88	2·81	2·48	11·16	5·96
„ Ca	12·9	12·7	9·6	11·2	13·1	12·5	12·6	9·1	10·2
„ Mg	2·3	..	..	..	2·3	2·3	2·5	2·5	2·3
„ Phosphatase	14·0	13·7	6·5	8·8	15·1	16·9	..	6·4	5·1
Sheep No. 61									
Blood: Inorganic P	2·22	..	4·23	..	3·13	2·70	..	7·47	4·12
Serum: Inorganic P	2·84	3·96	8·48	7·92	3·94	3·05	2·63	8·32	4·78
„ Ca	12·8	13·2	11·5	12·6	13·3	12·3	13·0	9·5	9·7
„ Mg	2·4	..	..	..	2·5	2·5	2·7	2·6	2·8
„ Phosphatase	15·1	13·5	10·1	9·2	12·7	13·5	11·7	7·5	6·6
Sheep No. 68									
Blood: Inorganic P	2·66	..	6·35	..	2·52	2·54	..	8·82	7·82
Serum: Inorganic P	3·48	4·56	9·56	10·60	2·94	3·03	2·58	10·36	9·46
„ Ca	12·8	12·3	10·2	..	13·8	12·6	13·0	9·8	10·3
„ Mg	2·4	..	..	..	2·4	2·5	2·7	2·7	2·9
„ Phosphatase	14·4	13·1	10·2	9·7	14·4	15·4	9·3	7·2	6·5

The amounts of food fed during each period were regulated according to appetite, but were kept in the same proportion, except during Period I when larger amounts of straw were consumed in proportion to the meals. The actual amounts per four sheep are shown in Table 2.

TABLE 2. *Daily Food-supply for 4 Sheep during the Different Periods*

	Period I	*Period II*	*Period III*	*Period IV*
Oat straw	1·75 lb.	2·00 lb.	2·00 lb.	2·50 lb.
Beet-pulp	2·50 „	5·00 „	5·00 „	6·00 „
Starch	2·50 „	2·50 „	2·50 „	3·00 „
Blood-meal	0·25 „	0·50 „	0·50 „	0·60 „
Dicalcium phosphate	..	100 gm.	..	..
Steamed bone-flour	..	..	..	148 gm.

As noted above, the appetites of the animals during Period I showed a marked decline, and the figures given for that period are the amounts fed at the end of the period at the time when two of the sheep were in the metabolic cages. The amounts of dicalcium phosphate and steamed bone-flour given as supplements in Periods II and IV, respectively, were adjusted to supply as nearly as possible the same amounts of P_2O_5. The actual amounts were 40·44 gm. and 40·76 gm. P_2O_5 from the supplements, respectively, per day for the four sheep.

The results of the balance trials with the two sheep (Nos. 54 and 61)

are summarized in Table 3, the figures being the daily net intakes and balances of N, CaO, and P_2O_5. The detailed figures are shown in the Appendix. As the two animals left varying amounts of meal and straw, which had to be weighed back and analysed, the net consumption figures for the periods show slight differences.

TABLE 3. *Net Daily Intakes and Balances*

Period	Supplement given	Nitrogen		CaO		P_2O_5	
		Intake gm.	*Balance gm.*	*Intake gm.*	*Balance gm.*	*Intake gm.*	*Balance gm.*
				Sheep No. 54			
I	Nil	4·64	−1·98	2·74	−0·62	0·52	−0·66
II*a*	DCP	12·27	+3·26	14·72	+2·20	10·79	+2·49
II*b*	DCP	12·46	+3·46	13·96	+1·90	11·03	+1·61
III	Nil	14·44	+2·28	6·23	−0·28	1·27	−0·32
IV	SBF	16·38	+3·49	20·82	+2·91	11·61	+1·02
				Sheep No. 61			
I	Nil	4·43	−1·08	2·73	−0·22	0·51	−0·47
II*a*	DCP	11·37	+2·67	13·58	+2·84	10·22	+0·26
II*b*	DCP	12·43	+3·49	13·90	+2·54	10·99	+1·68
III	Nil	15·23	+2·68	6·97	−0·27	1·33	−0·36
IV	SBF	16·37	+3·86	20·82	+3·12	11·61	+1·07

Both sheep No. 54 and No. 61 had shown a steadily decreasing appetite during Period I, and this, coupled with the fact that they were both on a negative nitrogen balance while in the metabolic cage, makes the figures for that balance period of doubtful value. During Period III, however, when the animals were again on the unsupplemented basal ration, both animals were eating well, and, as the figures in Table 3 show, had quite definitely positive nitrogen balances. The best measure of the relative efficiency of dicalcium phosphate and steamed bone-flour as phosphatic supplements will be obtained by considering the balance figures of Periods II*b*, III, and IV.

The differences in the balances of P_2O_5 between Periods II*b* and III show that sheep No. 54 retained 19·8 per cent. of the extra P_2O_5 ingested, and sheep No. 61, 21·1 per cent. In other words, on the average 20·4 per cent. of the P_2O_5 supplied in the form of dicalcium phosphate was retained.

Similarly the differences in the balances of P_2O_5 between Period IV and III show that sheep No. 54 retained 13·0 per cent. of the extra P_2O_5 ingested, and sheep No. 61, 14·0 per cent. On the average 13·5 per cent. of the P_2O_5 supplied in the form of steamed bone-flour was retained.

On the basis of these figures it would appear that, as a source of P_2O_5, dicalcium phosphate was utilized to an extent 50 per cent. greater than steamed bone-flour.

If we consider also the nitrogen balances we find that sheep No. 54 retained 27·7, 15·8, and 21·3 per cent. of the nitrogen ingested in Period II*b*, III, and IV respectively. The corresponding figures for sheep No. 61 are 28·1, 17·6, and 23·6 per cent., respectively. It would appear, there-

fore, that dicalcium phosphate exerted a more favourable influence on nitrogen assimilation than did steamed bone-flour. It is of interest to note that, whilst both phosphatic supplements exerted a favourable influence on the nitrogen balance, yet, in both cases, the actual digestibility of the protein was lowered.

Whilst both sheep showed a higher actual retention of CaO when receiving steamed bone-flour than when receiving dicalcium phosphate, it must be remembered that the former supplement supplied nearly 7 gm. more CaO daily than did the latter. On the basis of percentage retention of the CaO ingested there would appear to be little, if anything, to choose between the two supplements.

Summary

Experiments are reported with sheep on a basal ration markedly deficient in phosphorus to which in turn dicalcium phosphate and steamed bone-flour were added as phosphatic supplements.

With either supplement the sheep, which on the basal ration had shown a blood picture definitely indicative of phosphorus-deficiency, rapidly returned to normal, and showed normal levels for blood and serum inorganic P and serum Ca and phosphatase.

On the basis of balance experiments it would appear that phosphorus supplied in the form of dicalcium phosphate is utilized to an extent approximately 50 per cent. greater than when supplied in the form of steamed bone-flour. Further, dicalcium phosphate, added as a supplement to a phosphorus-deficient ration, appears to exert a more favourable influence on nitrogen assimilation than does steamed bone-flour.

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APPENDIX

Daily Net Intakes, Faecal and Urinary Excretions, and Balances of Sheep Nos. 54 and 61

Period		*Sheep* 54			*Sheep* 61		
		N	CaO	P_2O_5	N	CaO	P_2O_5
		gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
I	Net intake	4·64	2·74	0·52	4·43	2·73	0·51
	Excreted in faeces	3·15	3·18	1·16	2·88	2·80	0·96
	,, urine	3·47	0·18	0·02	2·63	0·15	0·02
	Balance	−1·98	−0·62	−0·66	−1·08	−0·22	−0·47
II*a*	Net intake	12·27	14·72	10·79	11·37	13·58	10·22
	Excreted in faeces	5·42	12·42	8·25	4·63	10·66	9·91
	,, urine	3·59	0·10	0·05	4·07	0·08	0·05
	Balance	3·26	2·20	2·49	2·67	2·84	0·26
II*b*	Net intake	12·46	13·96	11·03	12·43	13·90	10·99
	Excreted in faeces	5·72	12·03	8·89	5·12	11·33	9·28
	,, urine	3·28	0·03	0·53	3·82	0·03	0·03
	Balance	3·46	1·90	1·61	3·49	2·54	1·68
III	Net intake	14·44	6·23	1·27	15·23	6·97	1·33
	Excreted in faeces	4·44	6·19	1·58	5·73	7·00	1·68
	,, urine	7·72	0·32	0·01	6·82	0·24	0·01
	Balance	2·28	−0·28	−0·32	2·68	−0·27	−0·36
IV	Net intake	16·38	20·82	11·61	16·38	20·82	11·61
	Excreted in faeces	6·41	17·82	10·56	7·33	17·67	10·51
	,, urine	6·48	0·09	0·03	3·19	0·03	0·03
	Balance	3·49	2·91	1·02	3·86	3·12	1·07

THE CATTLE OF THE GOLD COAST

J. L. STEWART

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WITH PLATES 1, 2

THE cattle of the Gold Coast, from the coastal plains to the north of the Northern Territories, are unhumped, small, but of good conformation, and the bullocks weigh from 3 to 5 cwt. In general appearance they are not unlike miniature British Shorthorn cattle, hence the writer coined the name West African Shorthorn for this type of ox, a name by which it is now known in the literature of the subject. Like most other cattle throughout the world, the West African Shorthorn is not a pure breed, but a mixture of various types of cattle, though here and there are found varieties corresponding to one or other of the basic variations from which the present animal is derived.

Water Supply.—Cattle are confined to the northern half of the country, which is a vast undulating plain with savanna forest in the south, very open terrain on the northern frontier, and open plains on the sea coast. The rivers are slow or sluggish, and there is a long dry season from November to April, in the course of which the Harmattan, a dry, hot, parching wind blows steadily from the Sahara. The rainfall is 40–50 in. in the Northern Territories and North Ashanti, and about 20 in. on the coast; in the intervening rain-forest it varies from 60–90 in. Most of the rain falls from August to October, so that water-shortage is often acute in the dry season and in the spring. This has been a factor seriously inhibiting the development of the cattle industry, but is now being investigated by the Government. In a short time the live-stock areas will be well supplied with water.

Under present conditions, development of the live-stock industry is difficult. The southern area of the Northern Territories, Dagomba in particular, is most short of water for stock. In parts of Western Dagomba the cattle do not drink every day, as they have to travel long distances to get water. The anti-rinderpest immunization (Tamale reserve) was carried out in 1937 at Naboggo camp, four miles from the Pong-Tamale station, and close to the Naboggo River, which has been cleared under the Pong-Tamale tsetse-eradication scheme. The cattle had abundant water and no chance of picking up trypanosomiasis infection. Though the grazing at Naboggo was little, if any, better than in the places from which the cattle had come, the improvement in condition at the camp was marked. Observations were taken of the cattle when they returned to their homes; in many places the grazing was superior to that at Naboggo, but wherever water was scarce the cattle lost condition and soon reverted to their pre-camp state.

Lack of water has been partially met in some of the worst districts by moving the cattle to riverine areas, where dry-season camps are set up; but these can only be regarded as a temporary expedient, pending the proper development of water-supplies. Rivers in the Northern

Territories are heavily infested with tsetse-fly during the dry season; there is too great a concentration of cattle in one area, and the riverine grazing is none too good. Until well on in the Harmattan, fodder is to be found on the old grain farms and fresh grass in the stream-beds and swamps; from not later than mid-February, most fodder trees, of which *Afzelia africana* is the best, are in new leaf; lastly, a country which has an average annual rainfall of 45 in. cannot be really devoid of vegetation. Water is the essential, and when it becomes generally available for stock, improvement will be immediate.

Types of cattle.—The primary aim is to raise the weight of the West African Shorthorn bullock from 5 cwt. to 7 cwt., and this has proved to be quite easy, under existing conditions of husbandry, by means of the use of improved bulls. When the Department of Agriculture develops its 'mixed-farming' scheme, which makes a feature of fodder-production, it will be possible to increase the weight still further. Improvement must necessarily be limited by optimum native conditions.

The unhumped cattle of West Africa, which cover the Gold Coast, Togoland, Dahomey, French Guinea, the Ivory Coast (southern), Liberia, and extend into Senegal, Mauretania, the Sudan, and Nigeria, are a mixture of the three great types: the Hamitic Longhorn, which is the oldest African bovine, probably descended from the wild African urus; the Brachyceros or dwarf Shorthorn, imported from Asia many centuries ago; and the Zebu, more recently brought from Asia. In the north, the Zebu enters largely into the animal's composition and quite a big up-standing animal is produced, whilst in remote 'bush' areas and along the coast, where conditions are bad, the animal has become stunted and the dwarf Shorthorn blood is to the fore. The Hamitic Longhorn blood is found in most of the best and hardiest West African cattle, whether humped or unhumped, and where it is lacking the ox is also lacking in some essential, such as size, hardiness, or good conformation. Nearest to the pure Hamitic Longhorn is the excellent N'Dama breed. The more pure dwarf Shorthorn types are found in places like the coastal regions of the Western Province, west of Sekondi.

The fairly pure Hamitic Longhorn is the most satisfactory animal from a veterinary standpoint, as he has the highest resistance to trypanosomiasis and other enzootic diseases, and, moreover, is a good ox. The amount of Zebu blood which it is possible to infuse is limited by the degree of trypanosomiasis infection. There is much of the Zebu in the Gold Coast cattle, especially in the cattle of the northern parts of the Northern Territories; the rise in the withers, the dropped tail-head, the more prominent dewlap, the voice, the placing of the ears and the peculiar shape of the quarters, are all characteristic of the Zebu. What deceives the novice is the absence of the hump, an appendage which is not a point of all Zebus. The present grading policy is to restore to the general make-up of the Gold Coast cattle a higher proportion of that old indigenous African breed, the Hamitic Longhorn.

The Fulani have fixed several varieties of humped cattle by selection, but this has not been done purposively among the unhumped cattle, whose owners must be among the least informed stock-owners of the

world. Stock-breeding in the Gold Coast is at the stage where practically no owners understand that a good mature male is necessary for the production of good young animals, and where mating is left purely to chance. Laymen are apt to confuse the creation and establishment of a breed-type of cattle beast, which eventually produces animals that exhibit certain points and coloration, and continue to do so generation after generation, with the original basic ancestor breeds such as the Hamitic Longhorn. That this is not so can be understood when it is realized that a breed like the Aberdeen-Angus, an all-black, polled ox with typical conformation, is one of the most composite breeds in existence, being composed of selections from at least half a dozen earlier breeds and races.

There are nearly 200,000 cattle in the Gold Coast, of which 160,000 are in the Northern Territories, nearly 40,000 in the plains of the Eastern Province of the Colony, and a few scattered herds elsewhere. The best cattle are in the north-east of the Northern Territories, round Bawku, Zuarungu, and Navrongo, and in Dagomba round Tamale; they number about 100,000. These cattle are a mixture of Hamitic Longhorn and Brachyceros (Dwarf) with additional Zebu blood. All are unhumped, but in nearly every animal visible Zebu points are found. The Zebu, though susceptible to trypanosomiasis and other local diseases, is much more more resistant to rinderpest and is a good traveller, a most important point in West Africa.

From an archaeological point of view, the most interesting cattle in the country are those which have reverted to or remained the true Brachyceros (Shorthorn). Bad environment, bad tending, heavy protozoal infection, and inbreeding have caused the Brachyceros points to prevail, mainly because in these bad areas only a small animal can survive. They are dwarfed and stunted, and their measurements are identical with those of the old Celtic ox. The cattle are unthrifty and of no economic value in the markets. In Keta lagoon country these little cattle are hired to owners of coco-nut plantations, who tie them to trees for the purpose of producing manure. Such cattle are delicate, many of them are in a state of unstable equilibrium between life and death, and they are a nightmare to Veterinary Officers entrusted with the work of of immunizing them against rinderpest, as the slightest misjudgment of dosage of serum, heavy rain during reaction, or any abnormal incident, is liable to cause heavy mortality among such amazing animals.

Meat and milk.—Though a heavy admixture of Zebu results in what, to the average European, is sometimes a change for the worse in conformation, it does cause increased size and weight, and the more Zebu a cattle beast is, the more popular is it with the African, and the better is its market price at Prang and other centres. Meat is sold by weight in the markets, where there is no discrimination into quality and no 'beefsteak convention', as prevails in England, which inflates the price of certain parts of the carcass out of proportion to the rest, and leads to the breeding of cattle with the expensive parts of their anatomy very highly developed. The large Zebu has a great advantage economically: the larger the animal the better, and vice versa.

The Gold Coast and Ashanti are terribly short of fresh meat. There

is an abundant demand and a poor supply. Meat is expensive, the average being 1*s.* 6*d.* per lb., as against 4*d.* in Lagos and 2*d.* in Kano. No other British dominion or colony imports so much tinned or preserved meat. The Northern Territories and the plains of the Eastern Province have at present 200,000 head of cattle, some of which are too small and unsuitable for the markets. The number of cattle can be increased five times and the weight can be raised to a decent marketable standard.

The present position of the meat-supply of the Gold Coast is thus unsatisfactory. The annual import of Zebu bullocks from French West Africa, which has averaged 50,000 for a long time, is now decreasing and likely to decrease further owing to increased demand in the Ivory Coast and Senegal. Thus it is necessary to produce a self-sufficient supply of beef in the Gold Coast. Milk-supply is small, though there is considerable demand in urban areas. Nothing has been done to develop dairying, but it is hoped that this will be included in the 'mixed-farming' programme.

Husbandry.—Apart from water-shortage, bad husbandry is the most serious handicap to good live-stock. There are two methods of cattle-tending in the Gold Coast and one method of tending other live-stock. The first, and the more suitable, is that of hiring Fulani herdsmen to tend communal herds of cattle. The Fulanis are cattlemen, and this remarkable people have herded cattle for countless generations. They are aware of the basic facts of husbandry and the herds tended by them are the best in the country. The Fulani is specially useful in that he does understand that a good sire is essential, and his knowledge of fodder impels him to seek the best pastures. These people are sometimes referred to as aliens, but most of the Gold Coast Fulani are natives of the country, as were their fathers before them. In one district they are an integral part of the local native organization, and Fulani headmen are appointed by the local Chiefs. Unfortunately, in most cattle areas there are few Fulani, though they are gradually increasing.

The second method of husbandry is more common and consists in the herding of village and section herds by boys who are too small to wield a hoe, and who are transferred to cultivation as soon as possible. These boys exercise the minimum control over the cattle; they take their charges to graze in the nearest place where any herbage exists; they fail to recognize sickness before it reaches the lethal stage, and are in every way incompetent. The owners do not supervise the small boys properly and the result is bad husbandry. Calves in particular do not receive that individual attention which is essential, and a high mortality results. This small-boy control is the cause of many of the grade bulls issued from the Pong-Tamale farm becoming wild. These animals, being larger than normal, are inclined to frighten the small boys who, when they see them approaching, run away; the bull follows and learns the habit of chasing the boys; eventually the bulls chase all and sundry, so that many very quiet animals have developed into terrors of certain localities. Good bulls have had to be withdrawn for this reason. This illustrates the unexpected difficulties that are encountered in a primitive country. Here, again, progress is expected through the medium of the

Native Administrations. (For brevity, Native Administrations are subsequently referred to as 'N. A.')

Another peculiar system of cattle husbandry is that of the Konkomba tribe, who turn their cattle adrift at the beginning of the dry season to roam for themselves. This makes it difficult to get a good gathering for the annual immunization of young stock.

Considerable progress has been made in the control of the local live-stock trade through the medium of the N. A., several of which have issued orders preventing the sale or disposal of immature stock. The question of slaughtering young male animals for fetish sacrifices and funeral customs is more difficult, but attempts are being made to control this practice by substituting aged cows for young bulls. At N. A. conferences it has been stressed that the disposal of immature stock is squandering the country's resources, and this propaganda is making headway. Attempts are being made to stimulate a store trade by encouraging local men to buy immature animals from owners who wish to sell, and keep them until mature. A little progress has been made and further development is expected as the N. A. adopt suitable machinery for control.

Indirect Rule.—In the past, orders and regulations could be made, but administration of them was very difficult; now, the N. A. can administer such rules with ease. In this, as in other branches, the aim is slow progress and, if possible, voluntary suggestion by native authorities that such and such rules be made, for it is obvious that if restrictions are forced on the N. A., they will not be enforced with enthusiasm. It is necessary to avoid making the N. A. pass measures and administer rules that are in advance of the ideas of the more progressive elements. Pressure on the part of the Veterinary Authorities could undoubtedly have resulted in more and stricter rules being made through the N. A., but this policy would not have been effective in the long run.

Owing to the shortage of staff and the anti-rinderpest immunization scheme, Veterinary Officers have to travel their sections constantly, and that fact is responsible both for the lack of their educational influence and for the failure of the people to understand the object of many veterinary recommendations. Lack of intimate touch through not visiting the flocks and herds in their habitat is apt to create an impression among the people that Veterinary Officers are aloof officials, who make an annual visit to an area, immunize young cattle, and pass on elsewhere, their sole function being to immunize against rinderpest. Now that the number of Veterinary Officers has been increased, the country will be better travelled, and there is hope that enlightened ideas will spread and prevail.

Disease.—Permanent immunization of all cattle in the Gold Coast against rinderpest was begun in 1930 and ended in 1934, since when the 2-year-old cattle are treated annually at district camps. Prior to this, all cattle-improvement schemes were nullified by continual devastating outbreaks of rinderpest. Contagious bovine pleuro-pneumonia is the other killing epizootic disease, but an effective vaccine has been produced, and is available in quantity, so that this scourge can be controlled.

Before proceeding to methods of stock-improvement, it is necessary to deal with the limiting factor of trypanosomiasis, an enzootic protozoal disease transmitted by the tsetse fly. It is no exaggeration to state that all cattle in the Gold Coast are exposed to trypanosomiasis infection at some time or other, usually in the first or second year of life. Definite tsetse-belts, such as exist in East Africa, and have given rise to the popular conception of a belt of country made uninhabitable by fly, are uncommon in West Africa. The ubiquitous tsetse group is *G. palpalis*, which requires low shade and the presence of water. Thus, in the live-stock country, tsetse flies are confined to rivers and permanent streams in the dry season, and do not wander throughout the country, save at the period of flooding in the heavy rains of August and September, when they are driven into the surrounding country and travel up the temporary flood-period streams and watercourses, returning to their permanent habitat when the floods recede. It is during the dispersal phase that most trypanosomiasis infection occurs among cattle. Practical anti-tsetse measures consist of clearings at river-crossings and drinking-places to inhibit dry-season infection; but infection during flood periods is inevitable. The West African Shorthorn cattle possess a high resistance to trypanosomiasis; and this is the reason why Zebu cattle cannot be kept, save in the extreme north-east corner of the Northern Territories. Improvement measures are limited by the degree of trypanosomiasis infection.

It is well to stress the point that all resistance to trypanosomiasis is relative, so far as cattle are concerned. If tsetse infestation and consequent trypanosomiasis rise above a certain standard, cattle cannot be bred or maintained. No ox is immune to trypanosomiasis, though some are resistant, but this resistance can always be broken down, even in N'Damas, by an adverse environment, bad conditions, increased trypanosomiasis infection, &c. Many cattle have a high degree of resistance to the local strains of trypanosomes but little or none to strains of the same species of parasite in other parts of the country, even a few miles distant. In certain areas trypanosomiasis infection is so bad that no cattle can survive, and in other parts it renders the cattle practically useless.

Many experiments have shown that the N'Dama is the only cattle beast of West Africa which can usually stand up to infections of different strains of trypanosomes. Therefore it appears to be the most suitable bovine for improvement work in tsetse areas; hence special farms have been established to breed this valuable animal not only in the Gold Coast but throughout French West Africa.

Methods of Improvement.—Organization in the Northern Territories is carried out by a main Government farm at Pong-Tamale, the headquarters of the Department of Animal Health, where improved bulls of several types are produced. These bulls are issued to N. A. farms, which are self-controlled, but advised by the Department. There are now eight successful N. A. farms, and over twenty more are in process of establishment. The basis of these farms is a herd of the best local cows which can be bought, and the type of sire used for improvement depends on

the advice of the Department and the wishes of the N. A. officials, which are usually identical, but it is often necessary to counter the desire for Zebu bulls in unsuitable places and insist on a type more resistant to trypanosomiasis. The main purpose of the N. A. farms is to produce improved bulls for the village herds; these bulls are owned by the N. A. and cannot be neutralized nor disposed of by the villagers. The main Government farm also issues bulls to village herds direct, as more bulls are available than are required for N. A. herds; in 1936 seventy bulls were issued; in 1937 and after a minimum of one hundred will be available. Besides this scheme for bull production, the best young bulls are selected at the annual anti-rinderpest immunization of young cattle, are bought by the N. A., maintained in special bull farms in the interior, and eventually issued as communal sires if they turn out well.

The N. A. farm scheme has been criticized for its slow progress, and there is no doubt that had the farms been directly under Government and run by its officers, things would be more advanced, but extension beyond a certain number would have meant lack of sufficient direct supervision and loss of efficiency. The whole tone of the scheme, since it was started in 1932 to fit in with the new N. A. policy, has been to go slowly, and one of the difficulties has been to persuade the N. A. authorities that the farms are theirs and not the Government's; this problem is now solved and further extension will be rapid. Personal supervision by the N. A. authorities may not be quite so competent as personal supervision by Europeans, but it is preferable to have the whole of the country taking a leading part, willingly and interestedly, in the amelioration of their flocks and herds than to have acquiescence in the performance of a scheme which, to apathetic eyes, appears to have been designed for the amusement of alien Government officials. One immediate benefit is that the elders are now beginning to give freely their experience of local phenomena connected with animal husbandry, and this is very useful.

In the coastal area the organization is somewhat different, as active N. A. do not exist in the colony proper. A Government farm is under construction, and the farmers' associations will take the place of the N. A.

Imported cattle.—In the past, attempts were made to grade up the Gold Coast cattle by introducing exotic sires, Hereford, Shorthorn, Kerry, and Canary Island bulls having been imported for this purpose. Hereford and Shorthorn bulls were maintained in good health for eight years at Tamale in fly-proof loose boxes, but their progeny were a failure, because they could not tolerate enzootic protozoal infections. It is now realized that imported cattle are not successful, and that improvement must be confined to West African Shorthorn cattle, or to types of West African Zebu cattle whose progeny can thrive under Gold Coast conditions.

Sanga and Zebu.—When the humped Zebu is crossed with the unhumped West African Shorthorn an animal is produced which has no definite hump and, broadly, resembles more the West African Shorthorn than the Zebu, but, at the same time, has visible Zebu points. This type is known as the Sanga by Curson and Epstein, and when interbred,

breeds similar animals, reversion to the Zebu and to the West African Shorthorn not occurring. In many Northern areas this type is the local indigenous ox, and is a heavier and more suitable type for the meat market than the West African Shorthorn proper. These Sanga cattle live where tsetse infestation is light, and where cattle are exposed to trypanosomiasis infection only at the height of the rains, as, for instance, in the Kusasi district of the Northern Territories, which has a cattle population of some 30,000, and where three N. A. farms have been in existence for some years.

Some of the owners there prefer Zebu bulls, and pure Zebus thrive in that area. Two types of Zebu are used: there is White Fulani, a Nigerian type, which appears to have been created from the fusion of the Zebu proper and the Hamitic Longhorn, and weighs from 8½ to 10 cwt. These bulls are deep-bodied, of good conformation, and their female progeny are good milkers. They transmit their colour and conformation.

The other type used is the Sudanese or Short-horned Zebu, a fusion of the Zebu and Brachyceros (Dwarf or Pagan) strains. This ox is not unlike the White Fulani in body-conformation, has a similar lack of resistance to trypanosomiasis, and has been found suitable for the areas where Sanga cattle exist.

Zebu or Sanga cattle must never be introduced into or allowed to breed in unsuitable areas. There are places where, after introducing Zebu bulls, the people have produced Sanga cattle which do not thrive and are no improvement on the original West African Shorthorn cattle. There, every effort is being made to breed out the Zebu and to substitute cattle with a minimum of Zebu in their genetical composition. Much prejudice has to be overcome, as owners are frequently stubborn on this point.

The N'Dama.—Of greater importance for breed-improvement is the selection of local types. Of these by far the most important is the N'Dama, an unhumped animal of excellent conformation. The type was fixed in the Fouta Djalon mountains, possibly by the accident of isolation in a remote mountainous area. The N'Dama basic colour is dun, varying from a dark black dun, with a dun dorsal stripe, to light dun as a self-colour. There is a light dun ring round the nostrils. The breed is now spread over a large part of West Africa. It is as pure a type of Hamitic Longhorn as is available in modern times, but there is a possible admixture of Zebu and Brachyceros blood. Most of the N'Dama features are reproduced in the offspring. Crossing with a N'Dama both improves the inferior breed and at the same time increases its resistance to the ordinary bovine diseases of West Africa; in the latter respect the N'Dama is unique.

There are many improved cattle which, when crossed with West African cattle, improve them in size and conformation, but at the same time lower their resistance to local diseases and thus nullify the benefits of the cross. It is this lowered resistance to local diseases that in some areas renders abortive the improvement of the small West African Shorthorn by crossing with the Zebu, the resultant crosses proving too

susceptible to trypanosomiasis. Five years ago the Government Farm at Pong-Tamale started improvement work with N'Dama bulls, and experiments, followed by exhaustive field tests in moderate parts of the Northern Territories, have shown that N'Dama bulls vastly improve the local unhumped cattle and also tend to make them hardier. The local cattle have a high resistance to trypanosomiasis, but it is often very local, whereas the N'Dama appears to have a breed-resistance and to be able to resist not only the local strains of trypanosomes but those of other parts. Many N'Dama and grade N'Dama cattle have now been tried out under fairly adverse conditions in the Northern Territories and have given proof of their hardiness. The French are undertaking the same improvement through the N'Dama cattle and insist on their breed-resistance. The herd at Pong-Tamale was formed by the purchase of bulls and a few cows from the Ivory Coast, and by the selection of local Northern Territories cows of that variation. This herd is breeding true to type, and now numbers over fifty cows. The bulls weigh from $7\frac{3}{4}$ to $8\frac{1}{2}$ cwt.

A N'Dama-type herd is in process of formation at the N. A. farm at Wa in the north-west. This farm continues to be one of the best. It is well managed and has a bunch of cows most of which have been born and bred there. The N'Dama bulls have solved the improvement problem. Wa district is heavily infested with tsetse-fly and the cattle are inbred. Hence, blood from outside is desirable. All improved bulls, even West African Shorthorns, succumbed to trypanosomiasis when sent to the district until the N'Dama bulls arrived. They have thriven well, their progeny are improved, and are hardier than the local product. The Wa farm had a good effect on the live-stock of the countryside and has supplied many bulls to local herds. The farm has now a number of bulls on issue; there are five ready now, and further young bulls to come in the near future. The N. A. elder in charge takes full responsibility for the farm under the supervision of the District Commissioner and the Veterinary Officers. This elder also visits all Government bulls in the district and is, in fact, a most useful N. A. live-stock adviser. The Chiefs and prominent owners are emphatic that they wish development to be effected by means of N'Dama grading. The N'Dama bull at Sing near Wa is a particularly good one, and the herd is tended by a very good Fulani; the bull has been in splendid condition for two years, his calves are strong, hardy, and healthy, in spite of abundance of tsetse-fly in the grazing areas. So pleased are the cattle-owners of Kaleo division about the N'Dama bull there, that they are bringing their cows in from distances to be served by him; this is a great advance.

Working Oxen.—The West African Shorthorn, with a high Zebu strain, and Sanga bullocks make the best working oxen. Seventy head are maintained at Pong-Tamale for ploughing and carting. Each ploughman has two pairs which work during the cultivating season, from 6 a.m. to noon one day, and from 2 to 5 p.m. the next. These animals are selected from the best of the laboratory cattle after their period of serum production has ceased. They were purchased in the northern part of the Northern Territories where Sanga cattle are bred. Bullocks are broken in and

trained to work and then issued to N. A. farms, schools, the Department of Agriculture's farms, and others. There is a steady demand from surrounding villagers for the hire of ploughs and oxen when these can be spared by the farm.

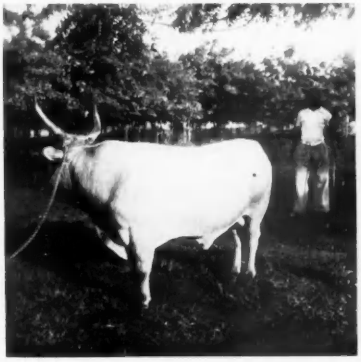
Other live-stock.—Although imported cattle are not a success, Large and Middle White pigs have been bred at Pong-Tamale for many years, and have had much influence in grading up the local pig. Rhode Island Red and Leghorn poultry are also successful, and most N. A. farms also run a poultry branch.

An interesting experiment has been carried out by the Department of Agriculture at its Assuansi Station in the forest near Cape Coast. A flock of sheep bought locally was established and fed on eight acres of land planted with *Centrosema pubescens*, which grows so luxuriantly in that humid climate that over eighty head of sheep have been fed on this small area and still cannot keep down the *Centrosema*. The experiment is combined with the form of mixed farming which imposes little or no work on the farmer; and better propaganda than that would be hard to find in the forest land of lotus-eaters. Whereas this scheme seems admirable in the forest area, it is unlikely to thrive in the savanna country, where *Centrosema* dies off or wilts in the dry season. If this Assuansi scheme is pushed, it might lead to the forest supporting its own sheep and goat populations.

(*Received November 11, 1937*)

West African Shorthorn (Bos compositus). Traces of constituent breeds can be seen

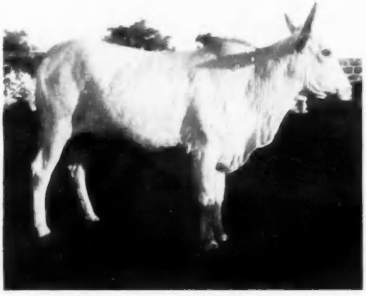
West African Shorthorn. Origin, mainly Brachyceros



The N'Dama, as pure a type of Hamitic Longhorn now to be found

Hamitic Longhorn sire, Brachyceros dam

Longhorned Zebu (type C). Origin, Hamitic Longhorn and Zebu



The Sanga, a cross between the West African Shorthorn and the Zebu

THE POTATO INDUSTRY IN JERSEY

D. SIMPSON AND T. SMALL

(States Experimental Station, Jersey, C.I.)

WITH PLATE 3

THE Island of Jersey has an area of approximately 54 square miles. Of this area nearly 10,000 acres on 1,700 holdings are under early potatoes, in patches which vary in size from a few perches up to a few acres. In addition to 2,000 regular agricultural workers, a further 2,000 or 2,500 English hands are engaged for the potato-lifting season, which lasts from May till early July. The Island imports annually 12,000 tons of fertilizers, valued at £100,000, and exports an average of 50,000 tons of early potatoes during the season mentioned. These figures indicate that the industry is of some magnitude in proportion to the area occupied.

About a hundred years ago the potato crop was found to suit the conditions in Jersey, and in time to be profitable, to such an extent that the cider-apple orchards, which covered much of the Island till as late even as the year 1880, began to be uprooted in order to allow potato-growing to be extended. Thus in 1875 the potato area was estimated at 4,000 acres, and in 1877 the exports amounted to 23,000 tons, valued at £230,000.

Disastrous seasons are mentioned in the century-old records of the Royal Jersey Agricultural and Horticultural Society, for example in 1886 when the disappearance of orchards was being lamented. Potato 'guano' was introduced to the Island in 1844 and in the following year potato disease is said to have broken out, but the recorder does not appear to connect these two events! [1]

Climatic conditions.—With an average rainfall of 33 inches, the climate is mild, without extremes of heat or cold, but a certain amount of humidity from the surrounding sea is present. In some years slight frost between March and May causes a setback to the potato crop. Mean soil temperature varies from 40–42° F. in winter, when growth of grass is seldom at a standstill, to 53–60° F. during May and June.

Soil.—A glance at a geological map [2] shows great variation in the kind of rock underlying the soil. The three largest areas comprise granite, shale, felsite tuff, and conglomerate. Stretches of the earliest land, around the north-west and south-east coast areas, are very sandy. The latter are rented at figures up to £25 per acre, as they carry a crop of tomatoes after the potatoes are lifted in May. The bulk of the land inside the coast strips (locally known as later land) is rented at about £9 per acre. On this the potato crop is ready to be lifted from the end of May until early July, and is followed by roots. The analysis of a typical 'late' soil (St. John) is given on the next page.

The so-called heavy soil is of the brick-earth type and does not approach a true clay soil. One of its usual characteristics is acidity, which appears to favour the early potato.

Variety of potato and cultivation.—The true 'Jersey' potato is the International Kidney, known locally as Benests, Parisiennes, de la

Hayes, &c., which has been in continuous use for well over 60 years, and in the Island still remains free from the effects of virus disease. The only changes of seed made are, in some cases, those from heavier to lighter soil, but seed is not taken from the very sandy areas. Other varieties of potato have been tried but found to succumb to virus after a few years' growing.

Chemical Analysis [3].

1. By hydrochloric acid

	Per cent.
Organic matter and loss on ignition	4·3
Oxide of iron and alumina	4·2
Lime	0·32
Potash	0·20
Magnesia	0·22
Sulphuric acid	0·26
Silica and insoluble silicates	90·2

2. By citric acid (1 per cent.)

Phosphoric acid	0·073
Potash	0·057

Mechanical Analysis.

	Per cent.
Coarse sand	7·9
Fine sand	51·5
Silt	28·0
Fine silt	7·2
Clay	0·5
Loss on ignition (organic matter)	4·3

The 'seed' tubers used are chiefly of ware size, about 3–4 oz. weight. They are put into trays on the field at lifting time, stored in open sheds or lofts till October, and are then turned out to have the first shoots broken off and set with the sprouting end upwards in the trays; these are then stacked in frost-proof lofts for the winter. Light and ventilation are regulated to produce a fairly sturdy shoot about 3 in. long by February–March, when planting takes place.

In preparation for potatoes, the land is usually skimmed during autumn to a depth of 3 in., when dung or a basal manure is turned in, and then ploughed in January–February to a depth of 10–12 in. by tractor or 4-horse plough. Thereafter a tilth is obtained by surface-cultivation and the potato fertilizer or 'guano' is harrowed in before planting, which is done on the flat. On the steep slopes the soil has to be dug by hand.

Planting takes place during February or early March when the soil is reasonably free-working. A special planting plough drawn by one horse makes a shallow furrow, into which the sprouted sets are placed, in a slanting direction, by men, women, and older children (Plate 3). The furrow is filled by the mould-board of the plough as it makes its next furrow and the sets are covered by only 1–2 in. of soil. The usual distances are 16–18 in. between the rows and 11–12 in. between the sets, but on the early sandy parts the rows are made closer. The quantity of ware-sized seed used is 36–40 cwt. per acre on average land. Before the shoots appear above ground the land is gone over by a hand implement or a light harrow, to break lumps and loosen the surface. Further cultivation during the growing-season consists of horse-scarifying between the plants to keep down weeds and open the surface until the crop is big enough for banking up, which is the last cultivation and is done by hand or horse-drawn implements. Spraying against blight is usually carried out in the period between banking up and lifting.

Manuring.—The typical farm soils receive cow manure about every three years. No definite system of rotation is practised, since potatoes are the main paying crop and are grown on as large an area of each farm as possible, but a common break in the potatoes (followed by roots as a second crop) is 3 years grass and clover, for hay and grazing, and one year grain, when the stubble is sometimes dunged. On the other hand, fields in favourable situations are known to have grown potatoes for 90 consecutive years. The sandy coast areas are manured with seaweed (vraic) almost every winter for growing early potatoes each year, and if possible a second crop of tomatoes, which is also early.

When basal manures are needed, apart from seaweed or dung, bone manures, mineral phosphates, potash, and organic nitrogenous materials are usually turned in, often as a result of soil tests made by the Experimental Station. In some cases green crops of turnips, mustard, or buckwheat are sown to be ploughed in for the next year's potato crop. The land is thereby kept in a fairly rich nitrogenous condition which, together with a generous quota of phosphate, favours early growth when the soil temperatures rise.

To force the crop, special 'compound' potato fertilizers are harrowed in just before planting. These are high in nitrogen and phosphate, a typical analysis being (per cent.) N 6, P_2O_5 8·5, K_2O 5, and they are used at the rate of 16–22 cwt. per acre, according to the nature of the soil. These mixtures are made for Jersey conditions and the nitrogen in them is derived chiefly from sulphate of ammonia, often with a little nitrate and some organic nitrogen in the better-class mixtures, the phosphate from superphosphate and the potash from sulphate and muriate. The residue of this fertilizer left in the soil after the potato crop has been lifted (in an immature condition with the haulms still quite green) serves to grow the second crop of roots on heavier soil, or of tomatoes on the lighter soil.

The yields of the potato crop vary from year to year according to the growing-conditions, but on the greater part of the Island the yield at the beginning of the lifting season in early June approaches 8 tons per acre and increases to 11 tons or more as the season progresses towards July. On the earliest, light, sandy soil the yield (in May) is much less, starting about 2½ tons per acre and sometimes rising later to 7–8 tons. The total cost of growing the crop (where the rent is £9) is on average soil around £55 per acre.

Marketing.—When the crop is considered fit for lifting it is, in most cases, dug by hand, or by machine in a few places, graded into ware and 'mids' in the field, and carted to the public weighbridge in St. Helier, where it is sold to merchants' buyers assembled there. The prices offered fluctuate, depending on the supply and on the demand which the merchants have from their wholesale customers in England. After sale the load is taken to the buyer's store where the produce is packed for export in 1 cwt. non-returnable barrels, or later in the season, when the produce is more mature, in 1 cwt. sacks. The grower is able to obtain cash on presentation of his weighbridge ticket at the store. The ticket shows the net weight of potatoes and also the price, marked on it by the buyer at the time of purchasing.

Some growers pack and export their own produce direct to dealers in England with whom they have previously made arrangements. A few growers have their potatoes sent over for them on commission, but the general method is by sale on the weighbridge [4].

The returns for weight and value of produce exported during the last 7 years are as follows:

1931	43,306 tons	£512,595
1932	49,486 ,,	£446,670
1933	65,850 ,,	£567,767
1934	58,619 ,,	£636,325
1935	80,468 ,,	£979,594
1936	58,161 ,,	£845,446
1937	55,701 ,,	£585,887

The potato industry has been found naturally suited to the climate and soil of Jersey, and has been extended as far as it can be, as a result of the fairly profitable years which occur at intervals. Britain is the only market. Possible checks to good seasons would be caused by severe frost during April or May, and neglecting to take precautions against blight; an outbreak in the Island of the Colorado Beetle might put an end to the trade until conditions again became normal.

Potato Blight (*Phytophthora infestans*).—No account of the Jersey potato industry would be complete without some reference to blight. The variety International Kidney produces high yields of excellent tubers which command a ready sale at remunerative prices, provided they are sound. Unfortunately the variety is very susceptible to blight and this, together with the mild, humid climate, often results in severe epidemics of disease which have disastrous effects on the markets.

The chief bugbear of the industry is the disease which appears in the tubers after lifting. The produce is apparently sound when dug and packed for export but it often develops blight on the markets before it is sold or consumed. Much progress has been made in recent years towards a successful solution of this important problem.

Spraying with home-made Bordeaux or Burgundy wet sprays or with ready-made wet and dry copper mixtures is widely practised by growers. It is recommended to give the first application before banking and succeeding treatments at approximately fortnightly intervals. This delays the onset and spread of blight and may suffice to keep the crop sound in some seasons. In other years, however, when climatic conditions are favourable to disease it is usual to find sprayed crops attacked in June when lifting is in full swing. Investigations showed that tubers dug when the fungus was sporulating on the haulms almost invariably developed blight later because they became contaminated with spores at lifting time (see Table 1). The crux of the problem was to prevent this contamination.

Experience proved that thorough and timely spraying delayed the appearance of blight until a good yield of tubers had formed. Once this stage had been reached complete destruction of the haulms would ensure sound potatoes. Cutting the haulms and leaving them on the field was effective, but this method has now been replaced by spraying with

sulphuric acid (B.O.V. of sp. gr. 1·70) at the rate of 4 gal. in 36 gal. of water. This spray is particularly suitable for Jersey, where the crop must be marketed quickly. Nearly 2,500 gal. of acid were used in 1936 and a still greater quantity in 1937. When the haulms are scorched at the proper time, i.e. whilst they are healthy, or at the latest when disease first appears, perfectly sound tubers are marketed.

TABLE 1. *Development of Blight in Tubers after Digging*

Condition of haulms	*Date when dug*	*Date when examined*	*Condition of tubers*		
			No. healthy	*No. diseased*	*Diseased (%)*
Severely diseased .	26.vi.33	3.vii.33	47	147	76
,, ,, .	26.vi.33	3.vii.33	55	65	54
,, ,, .	24.vi.32	30.vi.32	42	48	53
,, ,, .	7.vi.32	14.vi.32	190	56	23

If blight has been allowed to become prevalent in a crop, some loss is inevitable, but this may be reduced appreciably by scorching the haulms and postponing digging for 3 to 7 days. The shorter period is sufficient under dry soil and atmospheric conditions, but in wet weather a longer period is necessary. In one trial in 1937 the amount of disease developing in the tubers after digging was reduced from 35 per cent. to 1 per cent. by scorching the diseased haulms and delaying digging for 3 days. Such results have led to the adoption of a policy whereby the lifting of blighted crops is forbidden until precautions have been taken to reduce the risk of disease in the potatoes. This scheme penalizes the indifferent grower and encourages the careful grower, who is the mainstay of the market; it also tends to re-establish confidence amongst the merchants and to improve the future prospects of the industry.

As explained earlier in this article, growers save their own seed. Serious loss is incurred by contamination at lifting-time. Where sulphuric acid is not used, an alternative method is to dip the seed in a one per cent. solution of formaldehyde (1 gal. of 40 per cent. formaldehyde in 99 gal. of water) the same day as they are dug. The combined results of fifteen field trials were:

	No. of tubers	
	Healthy	*Diseased*
Dipped . . .	1,706	48
Undipped (controls) .	2,512	2,109

The treatment is simple, inexpensive, and harmless to the tubers.

Other diseases.—Black Scurf and Stem Canker (*Corticium solani* Bourd & Galz) is prevalent on seed potatoes, and in a wet cold spring it attacks and kills the young shoots and causes occasional 'misses' in the field. Common Scab (*Actinomyces scabies* (Thaxt.) Güss) is occasionally serious on a few fields, especially in a dry season, such as 1934. Stalk Break (*Sclerotinia Sclerotiorum* (Lib.) de Bary) attacks a few plants in wet seasons and is not important. Pink Rot (*Phytophthora erythroseptica*

Pethybr.) has been observed only once. Grey Mould (*Botrytis cinerea* Pers.) is often present on the foliage but causes no damage.

Virus diseases. Although the variety International Kidney has been grown in the Island for several decades it still produces remarkably heavy yields and does not appear to 'degenerate'. Other imported varieties quickly succumb to attacks of virus diseases. Little Potato (Physiological) has occurred several times recently. It is characterized by the development of numerous small new tubers close to the parent seed and by the absence of aerial haulms. Investigations have shown that the condition may be induced by applying heavy doses of naphthalene (often used to check wireworm) too near planting time.

Grateful acknowledgement is made to the *Evening Post*, Jersey, for the photographs reproduced in Plate 3.

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Planting seed potatoes in Jersey: the planting plough; sowing the sprouted sets

CITRUS CULTIVATION IN SOUTHERN RHODESIA

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WITH PLATES 4, 5

LESS than fifty years ago a small band of pioneers marched into Matabeleland and started to colonize the territory now known as Southern Rhodesia. In the earlier years the search for minerals came first and foremost, but, as always, in the wake of the miner came the farmer whose operations, although perhaps not quite so spectacular, are essential to any community. It was very soon discovered that the many varieties of citrus grew extremely well, but it was not until some twenty years ago that citrus cultivation on a commercial scale was begun.

The British South Africa Company was the pioneer of citrus cultivation on a commercial scale in the Colony, and it is the largest grower to-day, with some 90,000 trees on its three estates. The industry is yet in its infancy and the total number of trees in the Colony is comparatively small, but through the enterprise and foresight of the Company an experimental station with a staff of five fully qualified men was established in 1931 and since that date a considerable amount of research work has been done. Thus almost at the very outset a far-sighted policy was adopted for enabling the industry to be built up on sound foundations.

By far the largest citrus estate owned by the Company is situated in the Mazoe Valley about 30 miles from Salisbury, the capital of the Colony, and it was here that the experimental station was subsequently established. The bulk of the work has been carried out on this estate, but other estates and plantations are visited by members of the staff, and the results are made available to all growers in the Colony through the medium of the annual reports and by personal contact. The developments at Mazoe, and on the Company's estates generally, may therefore be taken to be an indication of the lines along which citrus cultivation is developing in the Colony.

It must be pointed out that the European population of Southern Rhodesia only just exceeded 55,000 at the last census, taken in 1936, so that even including the sale of citrus fruits to the mines for issue to native labour the local market is extremely limited. It is limited even further by the fact that the majority of residents have a few citrus trees in their gardens. Citrus, then, on a large scale can virtually only be grown for export; only about 6 per cent. of the total crop harvested at Mazoe is absorbed by the local market. The problems of an industry that grows citrus primarily for export to the British market are by no means the same as those in a country where the fruit is grown principally for the local market. Citrus grown for export has to compete in quality with fruit from other countries, and therefore it must be landed on the market not only in good condition but in an attractive manner.

Southern Rhodesia is a long way from Great Britain and the large European consuming countries, and the costs from grower to consumer

are considerable. With increasing competition and falling prices every effort has to be made to improve the quality of the product and to aim at the highest possible yield per tree in order to minimize the cost of production. Research in this Colony has been directed to these ends, and it is no exaggeration to say that good progress has been made.

It is proposed in this short article to deal mainly with field practice and the changes in it necessitated by the results of research. The problems that arise from the time the fruit leaves the grower until it reaches the consumer are treated very briefly, and reference to the economics of citrus-growing in the Colony has been omitted.

General conditions.—The climate of Southern Rhodesia is very favourable to the cultivation of most varieties of citrus. The commercial citrus orchards are found between the altitudes of 2,000 and 4,000 ft. above sea-level; the Mazoe Citrus Estate is at an altitude of 3,800 ft. The average annual rainfall in the citrus areas ranges from 30 to 36 in., and almost all the rain falls in the months of October and April. The annual mean of the maximum and minimum temperatures is about 65° F. and it is rare for frost to cause any damage. Hail has not been known to cause any widespread injury, but occasionally local hailstorms may affect a few groves. Wind is not an important factor in the Colony. Irrigation is essential for growing citrus on a commercial basis. The trees blossom in August, and from then until the rains break the temperature rises and the relative humidity falls. During September, October, and the early part of November, high temperatures are experienced with extremely low relative humidity, and it is during this period that irrigation is so essential. The crop is harvested from the end of April up to the end of September, according to variety. Soil types vary, of course, enormously in different areas, and even in different parts of the land under citrus in any one property, but generally speaking the soil is a medium heavy loam.

Nursery work.—For commercial purposes budded trees are grown almost exclusively; there are very few seedling trees.

The Mazoe Rough Lemon is universally used as a stock. This stock has so far proved excellent for the principal varieties grown; it is vigorous, of relatively uniform growth, and gives a good union. Mazoe Rough Lemon trees are to be found along the banks of the Mazoe river, and it is believed that their history dates back to the seventeenth century when Portuguese traders penetrated inland to this point.

Seed-beds are laid down in August, and the young seedlings transplanted into nursery rows the following February. The seedlings are usually of sufficient size to bud in December—approximately 18 months after sowing the seed—and the young trees are ready to plant out in their permanent habitat a year later. Drastic culling is undertaken at every stage, firstly to ensure that the seedlings are as uniform as possible before budding, and secondly that the young trees are uniform in growth and possess a fully satisfactory root-system before planting out.

The height of budding generally adopted is 9 in. above ground-level. In some of the earlier plantings low budding was practised, but subsequent silting up of the soil above the union has given rise to trouble.

Cultural conditions.—All types of citrus grow well, but only oranges and grape-fruit are grown to any extent commercially. Lemons and limes do extremely well, but are grown only for the local market; export to Europe is not an economic proposition, as the Rhodesian product, with its high transport costs, cannot compete with similar fruit from the Mediterranean countries, unless the conditions are exceptional. The Eureka and Villa Franca are the two varieties of lemon most commonly grown. Naartjes and Seville oranges are not grown commercially for the same reasons as lemons, although both varieties bear fruit of excellent quality.

The Valencia Late is the variety of orange grown chiefly for export. It is a hardy tree which does exceptionally well in Rhodesia; and it bears heavy crops of fruit, which is not only of excellent quality but travels well. The Washington Navel variety is very popular on the local market, but grown commercially for export it has not proved satisfactory. The British South Africa Company has replaced all the trees of this variety on its estates, with the exception of a few to supply local demand. On account of the distance from the market and the low prices realized overseas, high production per tree, and consequently low cost of production per case, are essential. The Navel tree is a shy bearer under Rhodesian conditions. Further, the overseas market demands a small or medium-sized orange, and when this variety was grown for export as much as 50 per cent. of the fruit had to be culled for oversize. The average size is largely dependent on seasonal conditions; the fruit ripens in May and early June and when the rains are prolonged and heavy rain is experienced in March and April the fruit continues to develop and to increase in size. Under such conditions the fruit is tender and liable to breakdown, so that a certain amount of wastage may occur in transit.

The Mediterranean Sweet, Jaffa, and Premier are the three mid-season varieties chiefly grown. The fruit ripens in May and June; the trees are medium to small in size and bear heavy crops of good quality fruit. The Premier orange, it should be stated, is a strain developed locally from a few trees with constant well-defined characteristics found in the Jaffa groves on the Company's estates.

The late varieties consist of the Valencia Late, Du Roi, and Leu Gim Gong. The Valencia Late has already been referred to. The Du Roi variety does well, but it is so similar to the Valencia Late that the two can hardly be distinguished. The Leu Gim Gong is grown only on a small scale at present, but shows decided promise.

Grape-fruit is grown only in certain areas, the variety being chiefly Marsh's Seedless. On the whole it cannot be said that the quality of the fruit is as good as that grown elsewhere, and the export is limited.

Citrus trees in Southern Rhodesia are planted 24 ft. apart. In the early plantings it was usual to plant 'on the triangle', with 19 trees to each irrigation-lead. This gave a most attractive regular appearance to the orchards but did not take into account the modifications in the slope of the land, with the result that in some cases the irrigation-fall was far too steep, and in course of time this led to erosion and difficulties in irrigation. The practice now is to plant the trees on the contour with

a fall of between 1 in 150 and 1 in 200, and the number of trees to a lead has been reduced from 19 to 14 or 15. Planting 'on the square' rather than 'on the triangle' is advocated, although it means that only 76 trees instead of 86 can be planted per acre. The adoption of the square system simplifies cultural operations, fumigation, and spraying.

Wind-breaks do not appear to be so essential in this country as in some others. In some of the earlier plantations wind-breaks of eucalyptus and cypress were put in at the distance usually recommended. Unfortunately this space proved insufficient when the trees in the wind-break grew up, so that the citrus trees in the outside rows began to suffer despite the periodic trenching and severing of the roots of the trees comprising the wind-break. Finally, it became clear that either the wind-break had to be removed or the first three rows of citrus trees uprooted. In these circumstances many wind-breaks have been taken out and no ill effects have resulted. At Mazoe there are practically no wind-breaks and there appears to be little need of them.

The practice of ploughing in a green crop is well known and well established. Green-manuring fulfils many important functions, in particular it supplies organic matter; it stimulates microbial activity, fixes atmospheric nitrogen when a legume is grown, checks soil erosion, and smothers weeds during the growing-period of the crop in the rainy season [1, p. 88]. In citrus groves there is danger that the cover crop will be in active competition with the trees, because when it is growing rapidly the orange tree needs its maximum supply of water, light, air, and plant-foods. The cover crops grown were principally sunn hemp, velvet beans, and sunn hemp and sunflower mixed. It was customary to plough the cover crop under, but this gave way later to disking it in. The use of the plough has been abandoned because it damages the shallow root-system of the trees. Experience has shown that the disadvantages involved in growing a cover crop between the trees during the rainy season outweigh the advantages, and the practice has been largely discontinued. The danger from soil erosion has been overcome by raising temporary bolsters in the groves for the duration of the rains, and the necessary humus is obtained by applications of kraal manure and compost. Weeds are kept down by hand-cultivation.

Recommendations for making synthetic manure were put forward in 1932 [1, p. 93], and this system has now been adopted as part of the routine practice on the Company's estates, as well as by some other growers. At Mazoe synthetic manure is made from two sources, firstly from river reeds, grass, sunn hemp, wheat-straw, &c., and secondly from the orange waste obtained after the cull fruit has been passed through the by-products factory. These sources of synthetic manure are a valuable addition to the supplies of natural manures available.

Various methods of irrigation have been tested at Mazoe, and as a result the furrow-system has been largely superseded by basin-irrigation. The latter system materially assists in checking the inevitably rapid flow of water down a long irrigation-lead and the resulting very uneven distribution of the water between the trees at the top and bottom of the lead. Further, any soil carried down by the irrigation-water is

only carried from one basin to the next, a maximum distance of 24 ft. Up to the present no indications of 'collar-rot' have shown up on account of the proximity of water to the bole of the tree, but it must be pointed out that the water does not stand in this position for any length of time.

In some of the groves at Mazoe a certain amount of erosion from irrigation and storm-water has taken place over a period of years, and trees in some of the low-lying parts of the groves have become silted up over the bud-unions. The trees in the eroded areas showed signs of distress rather suddenly some five years ago. Soil reclamation was undertaken and the results in improved vegetative and fruiting vigour were most marked. So rapid in fact was the response that it was thought that there must be some factor at work other than physical environment. About the same time the trees in certain other areas, where there was no question of soil erosion, also began to become unthrifty and lose vigour. It was established that there is a relatively sharply defined limit for the content of available nitrogen in the soil, and that if the content falls below that figure the trees begin to show distress, but pick up temporarily after the annual application of fertilizer (Plate 4, Fig. 1). The age of the trees varies from fifteen to twenty-five years and the available nitrogen reserves have gradually become more and more depleted. The effect of soil reclamation not only improved the physical environment but it raised the available nitrogen reserves above the critical point. Soil reclamation, and increased nitrogen dressings where no erosion was discernible, have had the most striking results in bringing the sickly trees into a condition of vigour and thrift.

Fortunately the areas in which silting up had taken place were small and localized. The effect of silting up is that a large percentage of the shallow root-system dies off and new roots are put out at a higher level (Plate 4, Fig. 2). Under local conditions, if the soil is allowed to silt up over the union and remain thus, the tree either becomes very unthrifty or dies, and even if the soil is removed it is not possible to save it. When the soil is removed from a silted-up tree a great many of the functional roots are destroyed, and the tree receives a serious set back until such time as it can renew or develop anew a root-system at the correct level. Consequently it takes some time to bring back a tree that has been silted up.

Research and the Industry

In the following very brief account of the work on citrus problems that is being carried out at the Mazoe Citrus Experimental Station reference is confined to the chief investigations and to the more important results that have been obtained.

Horticultural.—An experimental nursery and plot were started at Mazoe towards the end of 1931. It is too early to expect results, as the first trees were not planted out in their permanent positions on the plot until February 1934, and the research work undertaken is practically all of long range. Stock and scion relationships are one of the principal lines of investigation. It has already been stated that the Mazoe Rough Lemon is the universal stock in the Colony, but there are certain varieties,

such as the Jaffa and Premier, that do not give an entirely compatible union on this stock (Plate 4, Fig. 3). A series of double-budding experiments with various scions on Mazoe Rough Lemon with an intersect of various types is also in progress.

The improvement by systematic bud-selection of the chief varieties grown has been started, and a complete survey of all the trees on the Company's estates was undertaken with a view to determining the best forty or fifty trees as a source of bud-wood. The resulting trees are now 3½ years old and show considerable promise. At the same time specially selected bud-wood of various varieties of citrus has been successfully imported from California on more than one occasion, through the kind and invaluable co-operation of Mr. A. D. Shamel, of the U.S. Bureau of Plant Industry, Riverside, California. The trees from this bud-wood are growing rapidly and should prove of great interest and value.

An 'introduction garden' has been started in which an attempt is being made to collect together as many different strains and varieties as possible. Experiments are also in train on the transmission of undesirable characteristics in bud-selection with a view to determining which of these characteristics are transmissible.

Chemical.—A great deal of the work of the chemist has already been referred to indirectly in the section dealing with cultural methods. The soil reclamation, establishment of nitrogen deficiency at Mazoe, the preparation of pit-manure and modification of the cultural and irrigation practices with their very beneficial results, are in no small measure due to his efforts and co-operation with the field staff.

In the sphere of soil problems it was considered inadvisable to put down long-range field experiments on account of the variation of soils involved, but to deal rather with the specific problems with which we were confronted on the Company's estates. Hundreds of soil samples from all parts of the citrus areas on the Mazoe and Premier Estates were analysed, and with these results as basis it has been possible to give differential fertilizer treatment to the groves or even parts of groves, according to the needs which have been revealed.

Investigations have been in progress to determine: (*a*) the fertilizers required by the trees; (*b*) the best method of applying them; and (*c*) the correct time of application. As a result, considerable modifications of previous practices have been made. With a few minor exceptions it is now the custom to make all fertilizer application in the irrigation-water, thereby giving 'excellent distribution of the soluble nutrients in dilute solution to the active foraging zone of the tree roots' [2].

The time of application of fertilizers and manure is considered to be of paramount importance, and varying amounts of soluble nitrogenous and phosphatic dressings, depending on tree and crop condition, are applied in the irrigation-water as early as July to ensure an adequate reserve of the more essential plant-foods in the soil at the all-important blossoming period in spring. After the crop has been harvested in September the remainder of the fertilizer requirements is applied together with the standard dressing of some 200 lb. of artificial manure 'well in advance of the start of the wet season (October to November).

The manure is distributed entirely within the irrigation basin of each tree, where it is lightly forked in, care being taken to ensure that the bulk of the manure is distributed evenly in the area shaded by the tree' [2].

Experiments have been carried out over a period of four years to determine the effect of differential fertilizer treatment on the crop production and fruit-quality of bearing trees of the Valencia Late variety. The results show that nitrogen plays the most important part in maintaining tree vigour, high production, and good colour in fruit. Phosphorus has been found to be instrumental in setting heavy blossom and in improving the juice-percentage and the ratio of soluble solids to acid in the mature fruit. Potash, on the other hand, does not bring about a significant increase in soluble solids, but it does give rise to a somewhat increased percentage of acid in the juice. No treatment materially affected the fruit-size of the bulk of the crop, although the percentage of smaller fruit increased under high-nitrogen conditions, and the proportion of large and therefore potentially coarse fruit is greater under low-nitrogen conditions [2].

An attempt has been made to determine by analysis whether differential fertilizer treatment is reflected in any marked variation in nutrient intake of fruit and leaf-material. The conclusion has been reached that the analysis of nitrogen in juice and peel might serve as a valid means of estimating nitrogen requirements of citrus trees, but the estimation of potash, phosphorus, and calcium is less satisfactory for the purpose owing to modifying intake-relationships.

The presence of unthrifty trees carrying 'hard fruit' has been recognized at Mazoe for some years. In the past two or three years, however, it has gradually developed into a major problem. Trees suffering from this complaint are characterized by the development of small leaves with diminutive indentations on the ventral surface and die-back of the branches to a greater or lesser degree (Plate 4, Fig. 4). In severe cases the bulk of the crop is shed in October and November and the fruits remaining suffer from arrested development, malformation, the presence of gum pockets and a diminished juice-content (Plate 5, Fig. 5). Such fruits feel hard to the touch, and it is this characteristic that has given rise to the local name of 'hard fruit'. It has recently been established [3] that a deficiency or unavailability of boron in our soils is the underlying cause of this problem, and soil applications of borax have proved extremely effective in controlling the malady (Plate 5, Fig. 6). This discovery of the essential need of boron to the healthy development of the citrus tree is one which is likely to prove of major importance to all citrus-growers in the Colony.

Entomological.—Wherever citrus is grown on a commercial scale insect pests play a part of vital importance. They may so impair the vitality of the tree that it becomes unthrifty, or they may take toll of the crop on vigorous and healthy trees, causing serious losses. It cannot be said that Southern Rhodesia has more citrus pests to contend with than other citrus-growing countries; it is considerably better off than some.

The position at the moment is that we are able to secure reasonable

control of all our major pests with one exception. This state of affairs may not last, because our major pests may not continue to be amenable to the present methods of control, and at any time one of the numerous minor pests may develop and become of major importance.

The pest which has so far baffled all attempts at satisfactory control is the Cotton Bollworm, *Heliothis armigera* Hubn., which attacks the citrus trees every year between the latter half of August and the middle of October. Fortunately the attacks vary in intensity very considerably from year to year; sometimes the losses are negligible, but there have been occasions, such as the year 1932, when the losses were severe.

It is strange that this insect with its very wide distribution and numerous host plants should only have been recorded as a pest of citrus in southern Africa, but the reason may be that when the August generation emerges there is a dearth of other suitable host plants. It is believed that the moths are attracted by the scent of the blossom; oviposition usually begins about the middle of August and the caterpillars feed on the blossom and newly set fruit. In the most severe cases a tree can be stripped of fruit, but at the time the attack takes place there is a very great deal more fruit on the tree than it will bring to maturity, so that much of the fruit attacked would fall in any case during October and November when the normal drop takes place.

Much time has been devoted to a study of this problem, and a detailed account of the bionomics of the species in Southern Rhodesia has been given by Parry Jones [4]. It was hoped that this investigation would indicate how effective control could be obtained, but it did not do so. A study of the egg parasites *Trichogramma lutea* Girault and *Telenomus ullyetti* Nixon was then undertaken and, somewhat contrary to expectations, the results suggest that there may be a possibility of utilizing biological control measures as a means of preventing serious losses [2]. Efforts are now being concentrated along these lines in an attempt to secure adequate control of this troublesome pest.

In most citrus-growing countries there is usually at least one species of scale insect that constitutes a major pest. The particular species in Southern Rhodesia is known as Red Scale—*Aonidiella aurantii* Mask. It is widely distributed throughout the Colony and control measures are essential where citrus is grown on a commercial scale.

There are several well-known and long-established methods of control of this class of insect. On the British South Africa Company's estates all the trees are fumigated once a year by the 'Cyanofumer' method. 'Cyanogas' was used at one time by some growers, including the Company, but this has largely given way to 'Calcid'. Experiments have also recently been carried out with liquefied hydrocyanic acid gas, as used in California, but whereas this method has many advantages, the material is at present too costly. Oil sprays have been tried by some but they have not been adopted on any extensive scale. Fortunately, this scale has shown no signs of developing a resistant strain as yet and it is possible to obtain satisfactory control by fumigation.

It is common knowledge that when fumigation is practised, burning of the foliage of the tree may result from a variety of causes, and that

it is possible for this to occur without any injury to the fruit. During the last two years at Mazoe, with a dosage-chart that has been in use for the past eight years, the exact reverse has been noticed. Cases have occurred in which the fruit has been burnt, sometimes severely, without any sign of burning on the foliage. This problem is now under investigation.

Whilst effective control of Red Scale can be achieved on bearing trees, young non-bearing trees give considerable trouble. Fumigation of such trees is not economic or efficient, and no fully satisfactory spray has yet been found. The time of year when an application of spray is most likely to be effective has been determined in the course of a complete study of the bionomics of the insect by Parry Jones [5]. It is possible now to keep the pest in check, but it is costly because several applications are necessary, until a more satisfactory spray can be found.

Twelve years ago probably the most serious pest of citrus in the Colony was the Citrus Thrips, *Scirtothrips aurantii* Faure. A study of this insect was undertaken by Hall [6], and as a result certain measures were advocated which gave excellent control. These consisted in giving a double application of a lime-sulphur spray at an interval of nine days shortly after the petals had fallen. Some difficulty was found in maintaining the correct interval between the applications of spray on account of irrigation, particularly on a large estate. An attempt was therefore made to increase the duration of the toxic action of the spray in order that one application would suffice. For the past three years this has been done successfully by using colloidal sulphur in the spray.

Dusting with sulphur has been tried, but climatic conditions do not favour this method of control. It must also be pointed out that the thrips problem in this Colony is complicated by the development of a most unsightly tear stain from the original thrips scar on the fruit during the rains. A high degree of control is consequently necessary if material losses are not to be suffered from unsightly fruit, and the present method gives the degree of control needed.

Of other pests, the Citrus Aphis, *Aphis tavaresi* del. G., is controlled by the inclusion of nicotine in the lime-sulphur spray. If an attack develops before the trees are ready to be sprayed against thrips, a lime-sulphur-nicotine spray is used, but if, as often happens in an early infestation, the crop has not been harvested, lime-sulphur cannot be used, owing to the deposit which it leaves, and 'Pysect Concentrate' is applied.

Soft Scale, *Lecanium hesperidum* L., may be troublesome on young non-bearing trees. None of the proprietary oil sprays that have been tried has given satisfactory control, and it has been necessary to adopt the old remedy of resin wash, which does give reasonable results. The pest is kept well in check on bearing trees where an annual fumigation of such trees is the practice.

The False Codling Moth, *Argyroploce leucotreta* Meyr., is relatively common, but so far it can only be said to be a minor pest. This insect has been studied by Ford [7], and it was found that proper orchard sanitation was the most effective method of keeping the infestation within reasonable limits.

The Red Locust, *Nomadacris septemfasciata* Sert., has been prevalent in the Colony for the past five years, but fortunately no very extensive damage has been reported. Growers in the nearby territory of Portuguese East Africa suffered severe losses from this pest three years ago.

There are, of course, several other minor pests, but up to the present they have been of too little importance to require intensive study. At the moment, as stated previously, the only major pest which has defied all attempts at adequate control is the Cotton Bollworm.

Plant Pathology.—Plant diseases are fortunately not so prevalent in this colony as they are in many citrus-growing countries. There are nevertheless four or five of regular occurrence that are more or less troublesome. A full account of the diseases of citrus in Southern Rhodesia with detailed notes on those of greater importance is now in the press [6].

Tree diseases are not serious. It is only necessary to mention Psorosis, or Scaly Bark, of which a virulent strain occurs. Eradication measures are advised against this disease because the usual remedial treatments have met with little success. The manner in which infection in the field occurs is obscure, and the number of trees involved is relatively small.

Immature fruit is rarely, if ever, visibly attacked by fungi, and mature fruit is seldom infected whilst on the tree, unless it possesses some mechanical or physiological injury.

The fruit is harvested between the middle of April and the end of September, according to variety. During this period of the year the rainfall is negligible and the temperatures and relative humidity are relatively low. It seems probable that the comparative immunity to serious wastage is largely due to this favourable combination of circumstances. Occasionally heavy wastage, due chiefly to *Pencillium digitatum* Sacc, is found in the pack-houses or develops in early or mid-season fruit during transit, but this happens only after a prolonged rainy season, or when rain falls during the fortnight before picking. The principal variety grown in the Colony, the Valencia Late Orange, does not mature until the latter half of July, and the amount of wastage caused by green and blue moulds is negligible.

Citrus fruit is shipped overseas from Southern Rhodesia through two main channels. The quicker route is via Capetown and involves a rail journey of, usually, 6 days in ventilated fruit trucks, a short pre-cooling interval, and a voyage of between 14 and 20 days. The alternative is through Beira with a shorter rail journey of 2 days and a voyage of 30 to 33 days. At present there are no pre-cooling facilities at this port, and the fruit shipped through this channel is subject to greater extremes of temperature and more generally favourable conditions for the development of wastage than through Capetown.

In view of the length of the journey and of the time the fruit is in transit from grower to consumer, a considerable amount of work has been done on problems directly or indirectly associated with the carrying qualities of the fruit. The installation of an experimental cool-chamber at Mazoe has greatly facilitated the investigation of certain aspects of these problems.

FIG. 1. A. Advanced nitrogen-deficiency in an 18-year-old Valencia tree. Note thin foliage and short crop

FIG. 1. B. Vigorous Valencia tree under high nitrogen-treatment. Heavy crop almost obscured by dense foliage

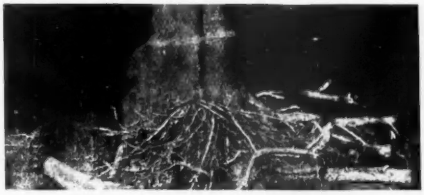

FIG. 2. Valencia Late on Mazoe Rough Lemon. This tree was silted up to within 2 in. of the union. The earth has been removed, showing the development of 'collar rot' and fibrous roots

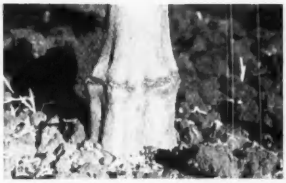

FIG. 3. Jaffa on Mazoe Rough Lemon, showing uncongenial union

FIG. 4. 19-year-old Valencia tree in an advanced stage of boron-deficiency. Exportable crop in 1937—nil

FIG. 5. A. Four fruits from same setting. Fruit on left from boron-treated tree; remaining three showing misshapen characteristics of boron deficiency

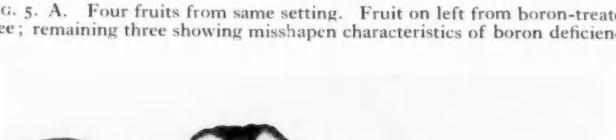

FIG. 5. B. Same four fruits showing internal condition. Note absence of seeds, rind thickening, and gumming in the boron-deficient fruits

FIG. 6. Badly affected boron-deficient tree about nine months after treatment with borax.
Total crop 1936 (before treatment)—107 fruits (80% gummed)
Total crop 1937 (after treatment)—1,941 fruits (no gumming)

Loss in weight of the fruit on all stages of its journey from grower to consumer has been studied, and the relation to wastage investigated. Temperature variations between Mazoe and Capetown were obtained by the use of recording thermographs in the railway trucks. The incidence and development of wastage under varying conditions of temperature, the influence of time in modifying the juice-content, and the ratio of soluble solids to acid in the fruit-juice, have been studied. Physiological injuries and break-down of the fruit have also been investigated. The results of this work to date will be found described in a series of papers by Bates, published in the reports issued annually by the Mazoe Citrus Experimental Station.

Experimental work on the so-called artificial coloration of citrus fruit, as practised in America, was initiated in 1930. A full account of this work has been published [1]. From 1933 onwards the process has been adopted as part of the routine on the Company's estates, and most exporters have since adopted it in some form or another.

Much information concerning the maturity tests taken at various times of the year on the different varieties of citrus grown has also been amassed, and routine testing of the fruit throughout the season has been initiated in all the Company's pack-houses.

Acknowledgements.—This short article cannot be concluded without a tribute to the work of the members of the staff of the Mazoe Citrus Experimental Station. The individual members of the Station, each in their respective spheres, are doing excellent work on the problems with which the citrus industry in this Colony is confronted. The work of the Station has been greatly facilitated by the closest co-operation that has been maintained with the technical officials of the Rhodesian Department of Agriculture, and we are indebted to these officials for the ready assistance which they have willingly afforded us at all times.

The photographs accompanying this article are by Mr. G. R. Bates of the Experimental Station.

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DEVELOPMENT OF LIVE STOCK IN TANGANYIKA TERRITORY

II. TANGANYIKA BREEDS OF SHEEP, AND MUTTON QUALITIES OF THE LONG-TAILED TYPE AND ITS CROSSES WITH BLACK-HEADED PERSIAN SHEEP

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In Tanganyika there are approximately two million sheep, owned almost entirely by natives. Unlike the neighbouring colony of Kenya the number of European-owned sheep is small and the number of 'grade' British sheep negligible. The sheep population appears to have decreased during the past eight years, and this fall has synchronized with a cycle of poor grazing years and a reduction of grazing areas; but this decrease now seems to have ceased.

The density of the sheep population varies considerably. The chief factors limiting numbers and governing distribution are the presence of tsetse flies, the incidence of strongylosis, and the scarcity of water. Cattle cannot live in thick 'fly' country, because they become infected with pathogenic trypanosomes that kill them. Sheep, owing to their smaller size, are less likely to be bitten by tsetse, and this circumstance, coupled with their greater reproductive rate, allows them to live under light 'fly' conditions, which would quickly kill off a cattle population. Also sheep-farming is not successful on the coast, on low-lying land, nor wherever a sufficiently heavy rainfall allows the growth of a rich vegetational cover, even though these areas may be 'fly'-free and support cattle. This is because such damp localities favour infestations of worm and fluke, which cause serious economic losses. For these reasons extensive sheep-rearing is necessarily confined to the areas of low rainfall and heavy overstocking in the Territory.

Tanganyika Breeds of Sheep

It is probable that all Tanganyika sheep have sprung from the same original hairy fat-tailed breed, though nowadays three distinct types can be identified: (1) the Masai or *short-tailed sheep*, (2) the black-headed Somali type, and (3) most numerous of all, the standard Tanganyika, or *long-tailed sheep*. The Masai is the largest sheep-owning tribe, and to suit its nomadic conditions a distinct type has been evolved. They are large, long-legged animals covered with a short hairy coat. Usually they are of a single colour with brown predominating, though white and brown and white sheep are seen, and as with all Tanganyika types some possess a woolly undercoat beneath the hairy outer coat. Mature fat wethers will weigh 100–110 lb. live-weight. They possess a deep wide chest, but are flat on the ribs; they are taller than the long-tailed variety, have smaller dewlaps, and stand higher off the ground.

As would be expected from the fact that they have to travel long

distances and exist in very dry areas, legs and shoulders are thin and muscular, carrying very little fat. The tail differs significantly in that it is shorter, of small circumference, and its fat is carried higher on to the rump than in the more common long-tailed type. It is from such Masai sheep that many of the grade flocks in Kenya have been bred.

The black-headed Somali type to be found in certain parts of this Territory is the offspring of the prepotent Somali sheep brought down from Somaliland into Kenya and Tanganyika by traders. They form the least common type.

The long-tailed or standard Tanganyika type comprises small stoutly built sheep possessing a good spring of ribs and a well-developed loin. They have large fatty dewlaps, and the rams show big pads of fat on each side of the nose, and another large deposit at the back of the head. The neck is rather long but very muscular, whilst the rump slopes downwards to the tail. The legs and shoulders are small and thin, and very muscular without surplus fat deposits.

The tail is usually very big and full of fat, and several different types can be identified. It is not known yet whether or not these different types of tail are inherited true to type, but one can classify them roughly into: (1) Small tails with fat carried high up on to the rump, as in the Masai sheep. (2) Long, broad, fat (shield-like) tails with a small pointed terminal portion that invariably folds upwards on to the main bulk. (3) Long, roundish tails tapering towards the end, reaching almost to the ground, and covered with fat over the whole length; and (4) tails which are broad, flat, and full of fat in the upper half but taper off into a thin, less fatty, lower portion; this may be an intermediate type between (2) and (3). These long-tailed sheep can be almost any colour or mixture of colours: white, black, brown, yellow, spotted, skewbald, piebald, or black and tan. The coat is composed of hairs often with a downy under-coat. Vestigial ears are occasionally observed, and since the size of the ear follows Mendelian segregation rules, all variations between no ears and perfect ears are to be seen.

Fat adult wethers will scale upwards of 80 lb. live-weight, but the rate of growth under ordinary conditions is slow, and full size is not reached until 4 years old, whilst fattening may be delayed even later. Birth-weights vary from 4–8 lb., and at one year lambs will reach 40–45 lb. Much of this slow development is due to poor nourishment or parasitic conditions; when brought inside and fed well, weights of 90–110 lb. can be reached at an earlier age.

Very few of the larger flocks of native-owned sheep look bright and active. Though there may be quite fat, healthy looking adults, the younger stock often look unthrifty, and snuffle along with their heads down, or stand with arched backs grinding their teeth. The almost general snuffling and stuffy noses are due to the larvae of *Oestrus ovis* (the sheep nasal bot-fly), which cause serious economic loss by reducing condition and causing general cachexia, though little mortality. Worms are the other retarding influence in young sheep, though it appears that with age the animals develop a certain tolerance to the effects of worms and nasal-fly larvae.

For many reasons it has not been Government's policy to contemplate the introduction of wool into native-owned flocks, but only to improve the mutton qualities of the local sheep. The first steps towards improvement are, obviously, to encourage disease-control and to provide adequate grazings. The development of a properly controlled system of rotational grazing would do much to improve the pasturage and condition of the animals, as well as to limit the intensity of worm-infestation to a level non-pathogenic to sheep. Since the mutton from fat-tailed sheep does not conform to the requirements of overseas markets, and the production of lamb requires better nutritive conditions than at present exist in this Territory, improvement in the mutton quality of the local sheep is intended only for the benefit of the internal trade.

Black-headed Persian Sheep

The Black-headed Persian is also a hair-coated sheep and has been greatly improved of late in South Africa. This breed is larger than the local native sheep, carries a very much more prominent brisket, and reaches maturity much earlier. Like the local sheep, Black-headed Persians are able to travel long distances, subsist on scanty pastures in very dry areas, and are highly resistant to tick-borne diseases, notably Heartwater. They differ from local sheep in the shape of their tails and by carrying a greater quantity of fat on the loin and rump. In a fat condition they also carry a greater subcutaneous covering of adipose tissue. It was thought that by introducing this breed, and using it to cross with native sheep, earlier maturing animals would result that would be no less hardy than the present type, and would still be in harmony with the hard conditions of life. The Veterinary Department has been experimenting with such cross-bred animals, and this paper attempts to provide quantitative support for the general conclusions reached 'by eye'.

The carcasses of well-nourished Black-headed Persians are nicely covered with flesh along the back, but have small legs and shoulders. At maturity these carcasses are covered with an excessive amount of fat, and owing to the large adipose deposits on the rump and tail-head, they lack symmetry. These deposits of fat not only cause an uneven appearance, but make the loins, which are usually well-developed and well-covered, appear sunken. In mature well-fed animals the carcass is spoilt by these wasteful and excessive fat-deposits, but in young animals they are very much smaller, so that lamb carcasses are more attractive. Similarly, these animals provide an edible and nicely fatted carcass at the end of a long dry season, when carcasses from improved mutton types would be devoid of fat. The carcasses of the local long-tailed sheep suffer from the same lack of symmetry as those of the Persian, because of similar large fatty deposits on the rump. However, there is a thinner covering of fat in the local long-tailed sheep, whilst the legs and shoulders are light, and the shanks completely devoid of fat. The neck is rather longer than in the Persian, but the sternum is less prominent and not so heavily covered with adipose tissue. As with the Persian, the carcasses of our mature long-tailed sheep are too fat to provide good mutton, but they are more attractive than the

former because they are less fatty. These animals also provide a nicely fatted carcass at the end of the dry season. In both breeds, however, as soon as the back-fat has been reduced to suitable dimensions, the legs and shoulders carry too little, and consequently dry out during roasting.

There is no marbling of the muscles in these long-tailed sheep, however well-fed they may be, although a certain amount of intermuscular fat may be deposited. The local long-tailed sheep and the black-headed Persian, therefore, carry not only too much fat, but the fat is also very badly distributed.

First crosses between the two breeds give carcasses that are intermediate in type, but the progeny of these first-cross ewes mated to a pure Persian ram (i.e. $\frac{3}{4}$-grade Persians) resemble the Persian in carcass-type and fat-deposition. This paper is concerned with mutton qualities of the local long-tailed sheep and $\frac{3}{4}$-grade Persians.

Experimental

The object of this work is to repeat with local sheep, so far as present facilities allow, the work of Hammond on British mutton sheep,[1] but Hammond's work has extended over many years and includes observations on a far more extensive scale than can be attempted in Tanganyika. In this preliminary study of the mutton qualities of native and grade-Persian sheep, 4 typical native sheep and 5 representative grade Persians were killed, and the live-weight records are the average of very much larger numbers. For studying the mutton, the sheep were slaughtered and dressed according to the usually accepted British method. All organs and joints were weighed, and the joints then dissected into muscle, fat, bone, and 'tendon and waste'.

The individual bones were all weighed and their linear dimensions recorded; the skeletal records will be dealt with in a subsequent paper.

In Tables 2, 3 and 4 most terms are self-explanatory, but the following qualifying remarks are made to avoid misunderstanding.

Skin and feet: the whole skin (including head skin) together with the feet, which were severed between the cannon and pastern bones.

The *Lights* consist of the contents of the thoracic cavity minus the heart, i.e. trachea, bronchial tubes, lungs, and part of the oesophagus.

Genitals. As these animals were all males, this term includes the penis, scrotum, scrotal fat-deposits, and atrophied or entire testicles.

Alimentary tract and its contents were determined by weighing together as soon as they were removed from the body. The contents were then washed out and the alimentary tract allowed to drain for 1 hour before re-weighing. The difference in weights is taken as the weight of the contents. The gut-fat was not removed in all cases, and so the weight of the alimentary tract includes the weight of it also.

Poll-fat represents the adipose tissue removed from the back of the head.

Dewlap-fat. The sheep here possess big pendulous dewlaps, which

[1] *Growth and Development of Mutton Qualities in the Sheep*, 1932 ed., Oliver and Boyd.

in fat animals become filled with adipose tissue. The term is used in the Tables to represent only that part of the dewlap-fat which is removed from the body when the head is severed. The remaining dewlap-fat is included in neck-fat.

The *Carcass* consisted of the dressed body of the sheep without the feet and head, but included the cannon bones.

The *Head* is severed between the atlas and the cranium, and was weighed after it had been skinned and the tongue removed.

The jointing of the carcass was always done by myself, and every attempt was made to make it as uniform as possible. It was done according to the plan outlined by Hammond in his work on British breeds, so that comparisons with his work are possible. The tail, owing to its great weight in fat-tailed sheep, hangs well out from the suspended carcass. It was found to be easy to separate the obvious tail-fat from the legs without cutting away any muscles from the leg or loin. In every case the junction of the caudal and sacral vertebrae was severed in removing the tail. The legs were then separated from the loin by a transverse cut on each side of the body, which divided the shaft of the ilium in its narrowest part and continued to the junction of the sacrum with the caudal vertebrae. The legs were then divided by cutting along the centre of the symphysis pubis. The shoulders were cut according to the standard trade method. The muscles attaching the shoulder to the sternum were first cut and then, by gentle pulling, were easily separated from the thorax. The knife was then passed round the scapula, severing the latissimus dorsi muscle, almost to the mid-line of the thoracic vertebrae; it was then continued round the scapula to the base of the neck, severing the trapezius and the brachiocephalicus muscles. This sounds more complicated than it is in practice. The neck was then cut off at the junction of the cervical and thoracic vertebrae, whilst the thorax was separated from the loin at the junction of the thoracic and lumbar vertebrae. The kidneys and kidney-fat were removed from the carcass before jointing, and were weighed separately. This fat is not included in the fat of the loin or thorax.

The various joints were weighed immediately after separation, and were then wrapped in damp cloths and placed in a refrigerator until required. The joints were dissected into their component muscles; subcutaneous and intermuscular fat were weighed together, and the bones were dissected as cleanly as possible, and then weighed. The tendons, ligaments, and scraps attached to the bones were recorded as tendon and waste. In the dissection of the joints a small but inevitable loss of weight took place and this represents the 'loss' in Table 4. The 'loss' in Table 3 represents the losses due to cooling and cutting into joints.

The sheep used in this study are divided into the following three groups:

Group 1. Includes 1 native and 2 grade Persian sheep killed at 1½ years old. One grade and the native were fed inside from 6 months old, whilst the second grade was reared entirely on grass. Their weights were respectively, 82, 72, and 57 lb.

Group 2. Two native and three grade sheep constitute this group, and all were killed at between 2 and 2½ years. One grade weighing 55 lb. at a year old was brought inside and fed hay *ad lib.* and 1 lb. of maize daily until he was killed at 90 lb. (at 2 years). The second grade was a ram that had been castrated late and possessed undesirable horns. He had received ½ lb. cottonseed daily from the age of 6 months in addition to normal grazing. At 2½ years he weighed 83 lb. The third grade had been reared inside under good conditions from birth; he weighed 106 lb. at 18 months and 109 lb. when killed at 2 years old.

One typical native sheep was brought in from grazing at 2 years old weighing 72 lb. and was killed at 2½ years weighing 84 lb. The other native had been reared inside from birth under good conditions; he reached 105 lb. at 21 months and was killed at 2 years old still weighing 105 lb.

Group 3. Contains only one mature native wether. He was brought in from grazing at 4½ years weighing 70 lb. and was then fed up to be killed at 5 years, when his live-weight was 90 lb.

It is thus seen that animals reared under different systems have been averaged together in the groups; this has been necessary because publication of the complete data would take up too much space. It is hoped that the averaged figures will represent sheep reared on grass, but finished off with a concentrate food and hay at night during the later stages of fattening.

Results

Rates of growth.—In Table 1 are summarized the results of live-weight records of some of the above and of many other sheep. Certain animals appear at several ages, but others only appear once. All figures are for animals not stall-fed.

TABLE 1. *Live-weights of Native and ¾-Grade Sheep (lb.)*

	Birth	*6 months*	*12 months*	*18 months*	*24 months*	*36 months*	*48 months*	*60 months*
Native . . .	4–8	24	43	62	70	78	85	90
¾-Grade Persian. .	6–8	30	58	69	76	90	ND	ND

These few figures, in conjunction with those given for the experimental sheep above, show that the ¾-grade black-headed Persian sheep is somewhat earlier maturing than the local long-tailed breed, and that normally the grade is a slightly heavier animal. However, it is obvious that there are earlier maturing strains amongst the local sheep, and it is probable that such strains, if segregated and bred from, would yield a better animal for mutton production than can be obtained by introducing Persian blood. Such strains of native sheep would yield an equally heavy carcass as the ¾-grade Persian, but without such a wasteful quantity of fat.

Actual and percentage weights of organs and tissues.—The figures in Table 2 give the weights of the different organs in the nine sheep dissected.

Owing to the variations in the contents of the alimentary tract it was decided to make all the calculations on the empty live-weight basis. In this work the carcasses were not allowed to hang overnight, because it was thought that greater accuracy would result from jointing within 3 hours of killing and then storing the joints in a refrigerator. At our normal temperatures putrefaction rapidly sets in if any part of the carcass has been incompletely cleaned of blood. All carcass-weights were therefore recorded before the flesh had cooled. The blood was collected in a big basin, and as all the sheep were killed after the Mohammedan fashion (i.e. by cutting the throat through to the backbone) very little blood was left in the carcasses.

TABLE 2. *Actual and Percentage Weights of the Organs and Tissues in the Empty Live-weight*

Animals:	1 Native		2 Grades		2 Natives		3 Grades		1 Native	
Age:	1½ years		1½ years		2–2½ years		2–2½ years		5 years	
	Gm.	%	Gm.	%	Gm.	%	Gm.	%	Gm.	%
Live-weight	32,688	..	31,730	..	42,925	..	42,676	..	39,365	..
Contents of alimentary tract	3,596	..	3,681	..	4,700	..	5,199	..	4,531	..
Empty live-weight.	29,092	..	28,049	..	38,225	..	37,477	..	34,834	..
Carcass (hot)	18,809	64·6	18,055	64·4	25,499	66·7	24,469	65·3	22,543	64·7
Blood	1,131	3·9	1,155	4·1	1,422	3·7	1,425	3·8	1,520	4·4
Skin (with feet)	2,610	9·0	2,235	8·0	3,162	8·3	3,097	8·3	2,869	8·2
Head (without skin and tongue)	1,833	6·3	1,835	6·5	1,790	4·7	2,355	6·3	1,942	5·6
Heart	206	0·7	170	0·6	197	0·5	147	0·4	162	0·5
Liver	338	1·2	375	1·3	346	0·9	446	1·2	507	1·4
Lights	433	1·5	366	1·3	505	1·3	344	0·9	481	1·4
Spleen	83	0·3	80	0·3	80	0·2	65	0·2	132	0·4
Genitals	143	0·5	140	0·5	345	0·9	526	1·4	86	0·2
Brain	82	0·3	91	0·3	87	0·2	96	0·2	97	0·3
Tongue	69	0·2	75	0·3	76	0·2	83	0·2	94	0·3
Poll fat	80	0·3	174	0·6	194	0·5	447	1·2	106	0·3
Dewlap fat	249	0·9	240	0·9	303	0·8	390	1·0	372	1·1
Omental fat	1,020	3·5	970	3·5	1,786	4·7	1,372	3·7	1,380	4·0
Alimentary tract	2,006	6·9	2,088	7·4	2,433	6·4	2,215	5·9	2,543	7·3

The figures in Table 2 indicate that there is no significant difference between the carcass-yields of the long-tailed and the ¾-grade Persian sheep. Further, the carcass-percentages for these animals compare well with those recorded by Hammond for animals in a fat condition. Hammond gives figures for a Shetland ram of 82 lb. live-weight, and comparison with the sheep in this study shows that the Shetland at a given weight yields a smaller carcass with larger proportions of head, 'pluck', and skin than either of the two types under investigation. These animals yielded much less blood than the two unimproved types examined by Hammond, but approximately the same percentage as he found in adult Suffolks. The skin and feet form a smaller percentage of the total body-weight in our two types than in British breeds, but this is to be expected because the animals of this series carried no fleeces. The head formed approximately the same relative proportion in these and the British mutton breeds but a smaller percentage than for the Shetland. Although the pluck (lights and heart) are proportionally greater in British mutton breeds, the percentages of alimentary tract, liver, kidney,

genitals, and heart are of the same order for British and for these two types.

The good comparison between the carcass-percentages of the local sheep and improved British mutton breeds is due to the very large fatty accumulations on the former. When an unimproved non-fat-tailed type like the Shetland is compared with our local breeds the percentage composition is greatly in favour of the fat-tailed types. Hammond points out that improved British types give nearly 10 per cent. more carcass than the unimproved breeds, and that this is 'largely due to an increase in the amount of fat in the carcass'. This is interesting because in these fat-tailed animals the tail forms 5–8 per cent. of the empty live-weight and 8–12 per cent. of the carcass-weight, and if the tail be removed the proportional constitutions of these local sheep correspond more closely to the unimproved Shetland than to the British breeds. Unless this fact is taken into account, the figures in Table 2 may give a totally erroneous conception of the mutton quality of local native and grade Persian sheep. Whereas fattening in British breeds consists in the laying down of fat in and between the muscles, in our local types it represents the deposition of large quantities of subcutaneous and caudal fat.

The figures in Table 2 show that there is very little difference in the proportional constitution of the bodies of the two local types. The lights and skin are perhaps slightly greater in the natives than in the grades, but the reverse appears to hold for the poll-fat.

The introduction of black-headed Persian blood has therefore not improved the proportions of the organs and tissues in the body of native long-tailed sheep.

Relative weights of the different joints in the carcass.—The data on this subject are given in Table 3, together with the absolute weights of the different joints.

TABLE 3. *Weights and Relative Proportions of the Joints in the Carcass*

Animals:	1 Native		2 Grades		2 Natives		3 Grades		1 Native	
Age:	1½ years		1½ years		2–2½ years		2–2½ years		5 years	
	Gm.	%	Gm.	%	Gm.	%	Gm.	%	Gm.	%
Carcass (hot) .	18,809	..	18,055	..	25,499	..	24,469	..	22,543	..
Neck . .	1,441	7·6	1,759	9·7	2,161	8·5	2,343	9·6	2,474	11·0
Shoulder . .	2,833	15·0	2,789	15·4	3,765	14·7	3,634	14·8	3,061	13·6
Thorax . .	3,678	19·5	3,715	20·6	5,924	23·2	5,965	24·4	5,125	22·7
Loin . .	2,944	15·6	2,992	16·6	4,404	17·3	3,819	15·6	3,720	16·5
Legs . .	4,150	22·0	4,494	24·9	5,345	21·0	4,823	19·7	4,686	20·8
Tail . .	2,519	13·6	1,377	7·6	2,680	10·5	2,730	11·2	2,532	11·2
Kidneys . .	70	0·4	69	0·4	75	0·3	71	0·3	79	0·4
Kidney-fat .	539	2·9	705	3·9	838	3·3	788	3·2	477	2·1
Loss . .	635	3·4	155	0·9	307	1·2	296	1·2	389	1·7

The proportional figures are calculated as a percentage of the carcass-weight. It is seen that for corresponding native and grade animals there is relatively little difference between the breeds, and certainly no indication that the introduction of Persian blood has increased the proportions of the more valuable cuts. It was stated earlier that the native sheep

possessed small legs and shoulders; the proportional amounts of these limbs have not been increased in the Persian grades.

Compared with improved British breeds these animals have relatively greater necks, but smaller amounts of legs, shoulders, loins, and thoraces. This is true even if the proportions are calculated on a carcass-minus-tail basis. Unimproved British breeds have been shown by Hammond (if his results be calculated to a percentage of the carcass minus head, as in this study) to have smaller percentages of loin, thorax, and kidney-fat, but greater proportions of leg, shoulder, and neck than improved breeds, as well as being much smaller in absolute size. If the figures obtained in this study be calculated on a carcass-minus-tail basis, the various joints are seen to occupy a position intermediate between the unimproved and the improved British breeds. This indicates that the local sheep are a stage further advanced than the Shetland for mutton production.

The figures in Table 3 show that the absolute and proportional amounts of tail in the carcass vary considerably between individuals. It appears that the shape and size of the tail have more influence on this factor than either age or stage of fattening.

If the younger and less fatted animals are compared with the older, and with the more fattened classes, it is seen that with age the proportions of neck diminish whilst there is also a decrease in the proportions of legs and shoulders, but an increase of loin and thorax. Similar changes are noted as a result of fattening animals of the same age. Further, the age-changes are intensified by fattening because fattening is itself a normal attribute of age. These observations agree entirely with those of Hammond for British mutton. Hammond also showed that improvement was accompanied by an increase in the upper parts of the legs and shoulders whilst the proportional amounts of the shanks were diminished. Our local sheep have not yet reached this stage in the evolution of mutton types, and it is partly on this account that the local breed possesses such poor quarters. The other important factor not possessed by local breeds is the power to lay down inter- and intra-muscular fat at an early age. In the local breeds the deposition of subcutaneous fat begins before there is sufficient fat in the limbs.

A glance at the absolute weights of the animals shows that as growth and fattening proceed, the greatest increase in weight is in the loin and thorax joints, with smaller increases in the legs and shoulders, and even less in the neck. There are individual idiosyncrasies that obscure these changes in certain individuals, but the general tendency is clear cut. It is not possible, from these figures, to study the rate of tail-growth, because individual variations in the shape and size of the tail obscure the changes due to age and fattening (e.g. the smallest native sheep had a heavier tail than the largest animal).

Composition of the joints.—In Table 4 is set out the composition of the joints in terms of muscle, fat, bone, and waste. Both the absolute and the proportional amounts are given. The composition of the carcass minus kidneys and kidney-fat is also shown. It is seen at once that these native and grade sheep differ significantly from the British breeds in the

relative amounts of fat and muscle in the different joints. This difference is most pronounced in the neck; whereas in British breeds this joint contains less fat than any other, this is by no means true of the local and grade sheep. The reason for this marked difference lies in the

TABLE 4. *Weights and Proportional Distribution of Muscle, Fat, and Bone in the Various Joints*

Animal:		1 Native		2 Grades		2 Natives		3 Grades		1 Native	
Age:		1½ years		1½ years		2–2½ years		2–2½ years		5 years	
		Gm.	%	Gm.	%	Gm.	%	Gm.	%	Gm.	%
Neck	Muscle	847	58·8	830	47·2	1,175	54·4	1,116	47·7	1,198	48·4
	Fat	342	23·7	668	38·0	652	30·1	915	39·1	935	37·8
	Bone	144	10·0	132	7·5	192	8·9	179	7·6	240	9·7
	Tendon and waste	99	6·8	116	6·6	130	6·0	111	4·7	86	3·5
	Loss	9	0·7	13	0·7	13	0·6	21	0·9	15	0·6
Shoulders	Muscle	1,721	60·8	1,560	55·9	2,113	56·0	1,708	47·0	1,906	62·3
	Fat	530	18·7	670	24·0	1,015	27·0	1,352	37·2	522	17·0
	Bone	400	14·1	383	13·8	443	11·8	419	11·5	432	14·1
	Tendon and waste	162	5·7	157	5·6	166	4·4	140	3·9	165	5·4
	Loss	20	0·7	19	0·7	29	0·8	16	0·4	36	1·2
Thorax	Muscle	1,885	51·2	1,529	41·2	2,519	42·5	1,948	32·7	2,595	50·6
	Fat	1,085	29·5	1,508	40·5	2,555	43·1	3,257	54·6	1,777	34·7
	Bone	382	10·4	362	9·8	508	8·6	443	7·4	541	10·6
	Tendon and waste	274	7·5	272	7·3	300	5·1	299	5·0	136	2·6
	Loss	52	1·4	45	1·2	42	0·7	18	0·3	77	1·5
Loin	Muscle	1,518	51·6	1,297	43·4	1,789	40·5	1,261	33·0	1,946	52·3
	Fat	1,038	35·2	1,425	47·6	2,251	51·0	2,242	58·5	1,178	31·7
	Bone	190	6·5	156	5·2	217	4·9	183	4·8	385	10·3
	Tendon and waste	131	4·4	107	3·6	128	2·9	122	3·2	197	5·3
	Loss	67	2·3	7	0·2	29	0·7	19	0·5	14	0·4
Legs	Muscle	2,676	64·5	2,632	58·6	3,168	59·8	2,658	55·1	3,028	64·6
	Fat	848	20·4	1,212	27·0	1,434	27·1	1,570	32·6	1,063	22·7
	Bone	494	11·9	512	11·4	552	10·4	460	9·5	514	11·0
	Tendon and waste	111	2·7	106	2·3	108	2·0	118	2·4	80	1·7
	Loss	21	0·5	32	0·7	34	0·7	17	0·4	1	0·0
Tail	Muscle	98	3·9	24	1·7	61	2·3	36	1·3	81	3·2
	Fat	2,365	93·9	1,326	96·2	2,556	95·4	2,654	97·2	2,408	95·1
	Bone	19	0·7	10	0·7	16	0·6	11	0·4	19	0·8
	Tendon and waste	25	1·0	14	1·0	35	1·3	19	0·7	9	0·3
	Loss	12	0·5	5	0·4	12	0·4	11	0·4	15	0·6
Carcass (minus kidneys and kidney-fat)	Muscle	8,745	49·8	7,872	46·0	10,825	44·6	8,727	37·4	10,754	49·8
	Fat	6,208	35·3	6,809	39·8	10,463	43·2	11,990	51·4	7,883	36·5
	Bone	1,629	9·3	1,556	9·1	1,928	8·0	1,695	7·3	2,131	9·9
	Tendon and waste	802	4·6	772	4·5	867	3·6	809	3·5	673	3·1
	Loss	181	1·0	105	0·6	159	0·6	102	0·4	158	0·7

tendency of British breeds to deposit fat in their large dewlaps and also in a ridge along the back of the neck to join up with the poll-fat.

Hammond found that there was a close correlation between the rate of post-natal development of a joint and its content of fat, the late maturing loin and thorax possessing the most fat. Whilst this is true generally for these fat-tailed sheep, yet native sheep Y and grade sheep Point both have higher fat-percentages in the neck than in the thorax.

The quantity of fat in a joint influences the percentages of muscles and bones. Hammond found that for British breeds the joints arranged themselves always in the order, neck, leg, shoulder, loin, and thorax, for descending muscle-contents. Owing to the larger and more variable nature of the fat-deposits, this sequence does not hold for grade and native sheep. In the animals examined the leg had the greatest percentage of muscle, followed by the shoulder or the neck. Whereas in British breeds the thorax always gave the lowest percentage of muscle, this is not necessarily so in fat-rumped or fat-tailed sheep, because the excessive deposit of fat on loin can cause a big depression in the percentages of its muscle and bone. In all joints these fat-tailed grade and native sheep show a higher percentage of fat than is met with in British mutton breeds. Similarly with the percentages of muscle and fat in the carcass, percentage of muscle always exceeds that of the fat in British sheep, but the reverse holds for fattened grade Persians, whilst in fattened native sheep the fat and muscle are present in about equal amounts. The large tail is the main cause of these differences in the proportions of muscle and fat, as can be readily seen from Table 5, for which the quantities of muscle, fat, and bone have been calculated as percentages of the carcass minus the tail. In this table the muscle exceeds the fat except for the

TABLE 5. *Weights of Muscle, Fat, and Bone, as Percentages of the Weight of Carcass minus Tail*

	Muscle	*Fat*	*Bone*
1 Native (1½ years) . . .	57·5	25·5	10·7
2 Grades (1½ years) . . .	49·9	34·8	9·8
2 Natives (2–2½ years) . .	49·9	36·7	8·9
3 Grades (2–2½ years) . .	42·2	45·3	8·2
1 Native (5 years) . . .	56·0	28·7	11·1
Shetland ram (5 years) . .	75·1	8·9	12·8
Soay ram (1–2 years) . .	70·6	9·7	15·6
Suffolk ram (4 years) . .	51·6	34·5	10·7

fat grade sheep in Group 2. Also indicated is the much finer nature of the bones in the local and grade sheep when compared with British breeds. This is a most important point, and all efforts to improve the size and quality of our local sheep should strive to maintain the bone-percentage as low as is consistent with the increased muscular development.

The figures in Tables 4 and 5 indicate that both native and grade Persian sheep carry too much fat. Further, the ¾-grades contain a higher percentage of fat than do the natives, with the corresponding inverse percentages of muscle. It is obvious from this that the quality of our local long-tailed sheep is not improved, but actually deteriorated, by the introduction of Persian blood. This conclusion agreed with the results of ocular observation, and the figures for unfattened sheep agree with the other practical finding, that fat-tailed sheep can yield a more suitable carcass if killed young, before the adipose deposits have become too big and wasteful.

Discussion

This work indicates that there is no significant increase in size as a result of crossing local long-tailed sheep with black-headed Persians, although the progeny are somewhat earlier maturing. The introduction of Persian blood changes the conformation towards that of the Persian breed, but it does not alter the organ weights or the carcass yields, nor does it alter the proportional carcass distribution in favour of the more valuable joints. The mutton quality of the joints and carcass, as judged by the ratio of muscle to fat, is deteriorated by the infusion of Persian blood into the local breed.

The figures for proportional distribution of the joints, as well as those for the weights of muscle, fat, and bone in the carcasses and joints, show that the local long-tailed sheep stand in great need of improvement if they are to become useful mutton animals. What, then, appear to be the best methods of effecting such an improvement?

Selection among the breed is the first course that must be adopted. This will allow an earlier maturing and a heavier type of sheep to be developed, but it cannot alter the unbalanced character of the carcasses. Our fat-tailed sheep do not possess good mutton conformations, and so selection and breeding by itself cannot achieve the desired result, though it will help to eliminate the more undesirable features and preserve the good points of the fat-tailed animal. Alongside the change in size and early maturity must come improvement in the environment (grazings and disease-control), because the improved sheep will not be able to exist under the old conditions.

The alteration of the carcass-proportions towards those of good mutton types may best be brought about by the introduction of a small, light-boned, British breed, famous for the quality of its mutton. The greatest argument against such a step is the unavoidable introduction of wool into the progeny. Wool is considered undesirable in the native-owned sheep of this Territory, because the development of a fleece would embarrass the animals in the heat; and as the wool would be of poor quality it could not command a high price. Further, the presence of wool would cause the animals to suffer much from thorns and grass seeds collected by the fleece, besides encouraging tick-infestation and scab. It can be argued, however, that provided the grading-up to the European sire is not carried too far, little wool need be introduced into the progeny. By selecting and interbreeding these low-grade sheep a mutton type possessing little wool should become fixed.

The introduction of British mutton breeds would be designed to improve the weights of the legs and shoulders, to introduce the ability to form 'marbled' joints, to encourage early maturity and the development of the correct amounts of fat and muscle in the more valuable joints, and at the same time to reduce the tendency to deposit subcutaneous fat unevenly and wastefully. The object of the crossing would be to retain the hardiness and constitution of the local sheep, and to retain its fine bone without introducing wool.

In choosing a British breed suitable for improving our local sheep,

small size, good mutton quality, lightness of fleece, and marked prepotency, with the ability to withstand hard conditions, must be the important factors. Breeds such as the Southdown, Ryeland, Dorset Horn, or the Welsh Mountain (black or white) suggest themselves. The first three of these breeds might perhaps introduce too large a disparity between the local conditions and the earlier maturity of their offspring. The Welsh Mountain sheep are of similar size and rate of growth to the local breed, carry small fleeces, are very active and good grazers, and yield good quality, small mutton. For these reasons this breed would appear to have the best chances of producing progeny in keeping with our hard local conditions.

Experiments are to be undertaken to determine the possibility of utilizing a British breed for improving the mutton qualities of our local sheep, but whatever breed is found to be the most suitable, the policy involved will be the same. It will aim at selecting the most desirable half-bred ewes and, by crossing them back to British and to local rams, to determine what mixture of native and British blood gives the most suitable type of animal. When this has been determined, 'grades' possessing the desired proportion of British blood will be interbred in the hope of fixing this particular combination and getting animals that will breed true to type.

One factor that will need special attention is the retention of the fat tail, but not the tendency to deposit fat in large masses over other parts of the carcass. The physiological significance of the fat tail is not known with certainty, and the reason for advocating its retention is the great importance attached to mutton-fat in many social ceremonies, and its wide use as a body- and hair-dressing by many tribes. This importance of sheep and sheep-fat to the native community is often not fully realized, and the immediate breeding out of the fat tail would meet with considerable prejudice and antagonism.

Summary

The black-headed Persian has been used in an attempt to improve the mutton qualities of Tanganyika sheep, and descriptions, drawbacks, and rates of growth have been indicated. The ¾-grade Persian appears to be a slightly heavier animal than the native sheep and somewhat earlier maturing, but to have a poorer fat-distribution and a conformation nearer to the Persian breed.

The introduction of Persian blood has not altered significantly the weights and relative proportions of the different organs, nor the carcass-yields. It has not had any influence on the distribution of carcass-weight among the various joints, and has not improved the proportions of the more valuable joints. The joints and carcasses of the grade Persian sheep contain much more fat than do those of native sheep. Judged by the muscle-fat-bone ratio, the Persian has produced a carcass inferior to that of the pure Tanganyika breed.

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THE CEREAL RUSTS IN CANADA[1]

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Introduction.—The cereal rusts constitute one of the principal hazards in cereal production in Canada. The distribution of these rusts in Canada may be better understood if some of the topographical and geographical features of the country are first mentioned. The Prairie Provinces, Manitoba, Saskatchewan, and Alberta constitute a vast plain of level or undulating surface. There are no forests in the cultivated region, but small wooded areas, and clumps of trees planted as windbreaks, are scattered over a considerable part of it. To the west lies British Columbia, separated from the Prairie Provinces by high mountains, the Rockies. It is a mountainous province, and the arable land is confined to rather small, isolated units. To the east of the Prairie Provinces lies Eastern Canada, comprising Ontario, Quebec, and the three Maritime Provinces. A stretch of forests and lakes, a thousand miles or more in width, separates the Prairie Provinces from the cultivated area of Eastern Canada. The eastern provinces have a diversified topography.

In the Prairie Provinces over 90 per cent. of the cultivated land, approximately 36,000,000 acres, is sown to cereals; in British Columbia, 173,000 acres; and in Eastern Canada, 6,000,000 acres.

To the south of the Prairie Provinces lies adjacent a still greater cereal acreage in the United States. This is substantially the same in character as the Prairie Provinces. There is thus an almost continuous expanse of cereals stretching from the Peace River Valley in northern Alberta to Texas in the southern part of the United States, a distance of 2,300 miles. The crops mature progressively later from south to north, and no pronounced physical barriers intervene to prevent the dissemination of spores throughout this vast area. With rather frequent winds from the south, the cereal rusts, particularly stem rust of wheat and oats, have an opportunity for uninterrupted spread such as exists in few parts of the world.

The spread of rust spores from the United States into Eastern Canada and British Columbia has not been fully investigated. As there is less acreage devoted to cereals and more obstructions to spore dispersal in both parts, it seems probable that the spread from south to north is much less pronounced than in the Prairie Provinces.

In Canada spores are apparently largely prevented from passing from British Columbia and from Eastern Canada into the great wheat-growing belt of the west by the natural barriers already mentioned. This seems to be particularly true in regard to British Columbia. A relatively small number of collections of stem rust of wheat have been made in British Columbia during the past eighteen years, but, of the isolations made

[1] Contribution No. 525 from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada.

from these collections, over one-quarter have proved to be races quite unknown in any other part of Canada. It seems probable, therefore, that rust spores seldom reach the wheat-fields of Alberta from British Columbia. Whether they are also as effectively prevented from spreading into the Prairie Provinces from Eastern Canada is not so clear. Results presented in a later part of this paper seem to show that there is not a very free exchange of spores between these two regions, as a number of races of wheat stem rust, such as races 35, 63, 64, 74, 75, 77, 83, 84, and 89, and a few of oat stem rust, such as races 9 and 10, have been collected in Eastern Canada but have never been found in the Prairie Provinces.

Distribution, Perpetuation, and Losses due to Cereal Rusts

Puccinia graminis Pers.—Stem rust occurs in every province of Canada. Its geographical distribution coincides in general with that of its host plants. It has been collected as far north as Churchill, Manitoba, which is 435 miles north of the present cultivated area in Manitoba. At Churchill the mean temperature for the year is 17·7° F., and for the months of July and August, 53° F.

In Western Canada the barberry is practically non-existent and, as far as known, the uredial stage of stem rust does not survive the winter. According to results obtained by Craigie [1] 'the initial infections of stem rust in Western Canada seem to arise from spores brought hither by air currents, presumably from infected areas south of the international border', where crops mature earlier than in Canada. He points out that in each year urediospores can usually be detected in the air by means of spore traps two weeks or more before rust infections can be found in the field.

In both Eastern Canada and British Columbia the common barberry is present and undoubtedly plays a part in the introduction of new races of stem rust (Table 7, p. 135). It is not known definitely whether or not the uredial stage of stem rust can survive the winter in these two parts of Canada. Probably it does not.

Stem rust is extremely destructive to wheat and oats in Manitoba and eastern Saskatchewan. In western Saskatchewan and in Alberta the outbreaks are less frequent and less severe. Only in occasional years has stem rust caused material damage in Alberta. In the Peace River District in northern Alberta stem rust is known to have occurred only in one year, namely 1927, a year of severe infestation throughout the Prairie Provinces.

The calculated average annual loss in Manitoba and Saskatchewan due to stem rust of wheat from 1925 to 1935, and to stem rust of oats from 1929 to 1934, is given in Table 1. The calculations were made by Greaney [2] and are based on results obtained from field experiments. In years of severe epidemics losses have been very great. In 1916 the reduction in yield of wheat was estimated at 100,000,000 bushels [3], and in 1935, at 87,000,000 bushels [2]. Although barley is at times very heavily attacked by stem rust, it generally matures earlier in the season than wheat or oats, and so normally does not suffer so much injury.

The average annual monetary loss from all cereal rusts in the three Prairie Provinces between 1925 and 1935 is conservatively estimated at over $40,000,000 [2].

TABLE 1. *Average Annual Loss in Manitoba and Saskatchewan from Wheat Stem Rust and Oat Stem Rust*

Period	*Crop*	*Average annual loss in bushels*	*Average annual loss in dollars*
1925 to 1935	Wheat	35,518,000	30,784,000
1929 to 1934	Oats	8,334,000	2,041,000

Puccinia triticina Erikss.—Leaf rust of wheat occurs on wheat in Canada wherever this crop is grown. It always appears in the Prairie Provinces a week or more earlier than stem rust. As urediospores can usually be detected in the air by means of spore traps a week or two before infections can be found in the field, the inference is that the early infections are due to wind-borne urediospores.

In years of severe infection this rust attains a severity of from 30 to 80 per cent. infection on wheat leaves in the Prairie Provinces, and from 60 to 90 per cent. infection in Eastern Canada. From results of experiments in the field at Winnipeg in 1934 and 1935, in which the control plots were dusted with sulphur, Greaney[1] computed that with a 40 per cent. infection on the leaves of a spring-wheat variety (R.L. 716) there was a reduction of 18 per cent. in the possible yield. In Canada infection always appears a short time before the wheat plants come into head. The percentage of infection on the leaves varies from season to season. It appears to be less when temperatures are very high [4]. As it rarely falls below 10 per cent., and often rises to 60 or 80 per cent., it seems safe to infer that leaf rust brings about appreciable yearly losses in this country.

Puccinia glumarum (Schm.) Erikss. and Henn.—Stripe rust has a restricted distribution in Canada, being confined to British Columbia, Alberta, and the western half of Saskatchewan. In the two latter provinces it is of limited occurrence and of little or no economic importance. In British Columbia, where some winter wheat is grown, it occasionally becomes destructive.

The gradual diminution of stripe rust from west to east is obviously not owing to lack of suitable host plants in the Prairie Provinces, as the most congenial grass host of this rust, *Hordeum jubatum* L., is ubiquitous. Sanford and Broadfoot [5] found that urediospores of this rust are capable, at least occasionally, of surviving the winter in Alberta, although they did not observe that the rust spread from such survivals.

Both greenhouse tests and field observations seem to suggest that in Canada the range of this rust is limited by climatic conditions. Studies carried out in the greenhouse by Newton and Johnson [6] showed that stripe rust is extremely sensitive to high temperatures. They found that

[1] Unpublished data by Dr. F. J. Greaney, Dominion Rust Research Laboratory, Winnipeg, Canada.

wheat plants susceptible to stripe rust at temperatures of 50° F. to 60° F. developed resistance at higher temperatures, becoming extremely resistant at 78° F. Infected plants kept at 78° F. for 12 hours each day became resistant even when, during the remainder of the day, they were returned to a temperature congenial to both host and parasite. These workers made a study of the temperature in the Prairie Provinces and British Columbia of the two hottest months, July and August, of each year from 1919 to 1933 to ascertain if a relation similar to that found in the greenhouse could be discovered between the occurrence of this rust in the field and the temperature prevailing during those two months. It was found that in British Columbia, where this rust is most common, the mean maximum temperature during July and August was 73·8° F., whereas in Alberta it was 77·1° F., in Saskatchewan 79·2° F., and in Manitoba, 79·6° F. Greenhouse experiments showed that a temperature of 78° F. for 10 to 12 hours each day rendered a susceptible host plant resistant to the rust, even when the temperature during the remainder of the day was congenial to both host and parasite.

In British Columbia summer temperatures, although lower than those prevailing in the Prairie Provinces, nevertheless rise above the optimum for the development of stripe rust, and cause a decrease in the abundance of stripe rust during the mid-summer period. With the coming of lower temperatures in the autumn the amount of rust again increases.

In Alberta and western Saskatchewan it is only in the autumn that stripe rust becomes prevalent, that is, at a time when the day temperature has become lower. As already mentioned, stripe rust has never been found in eastern Saskatchewan or Manitoba. The high day temperatures which prevail in the eastern half of the Prairie Provinces during the summer months seem to inhibit its development.

Factors other than temperature undoubtedly play a part in limiting the distribution of stripe rust in Canada. For example, mountain ranges seem to form an effective barrier against the spread of inoculum eastward from British Columbia. The amount of inoculum produced in Alberta and Saskatchewan is limited, and the lateness of the season at which it is produced seems to prevent stripe rust from spreading very far eastward before low temperatures in the early winter kill the hosts and render further spread impossible.

Puccinia coronata Avenae Erikss. and Henn.—Crown rust is fairly widely distributed and of considerable economic importance in Eastern Canada, but only occasionally does it become prevalent in the Prairie Provinces. It occurred in epidemic form in Manitoba and Saskatchewan in 1927 and again in 1935, and, in conjunction with stem rust, brought about reductions in yield of oats up to 50 per cent. As with leaf rust of wheat, so with crown rust of oats, development seems to be somewhat adversely affected by very high temperatures [4]. In Western Canada crown rust is not known to overwinter in the uredial stage. In the milder parts of Eastern Canada there is the possibility that it may overwinter, but, so far, evidence that it does so is lacking. Crown rust is known to spread from buckthorn hedges every year both in the Prairie Provinces and Eastern Canada, but, in years of heavy infection in the Prairie

Provinces, it is so widespread and abundant that local foci of infection can scarcely account for its prevalence. It is very probable that inoculum blown in from the south is responsible for such outbreaks.

Puccinia anomala Rostr. and *Puccinia dispersa* Erikss. and Henn.—Leaf rust of barley and leaf rust of rye are generally of minor importance in Canada.

Distribution and Prevalence of Physiological Races of Cereal Rusts

Physiologic specialization in the cereal rusts has received such world-wide study that most of its salient features are well known, as is also its significance with respect to breeding for resistance in cereals.

On account of the economic importance of stem rust in Canada, the study of physiologic specialization in this rust has been carried on for a longer period than in any of the other cereal rusts, although in recent years specialization in *P. triticina*, *P. coronata*, *P. glumarum*, and *P. anomala* has received considerable attention.

For the determination of physiologic races within rust varieties use has been made of keys developed by Stakman and Levine [8] for physiologic races of *P. graminis Tritici* Erikss. and Henn.; by Bailey [9] for *P. graminis Avenae*; by Johnston and Mains [10] for *P. triticina*; by Murphy [11] and Peturson [12] for *P. coronata Avenae*; by Gassner and Straib [13] for *P. glumarum*; and by Brown [14] for physiologic races of *P. anomala*.

Puccinia graminis Tritici.—An extensive survey for physiologic races of stem rust of wheat has been carried out in Canada since 1919. In Table 2 are enumerated the races isolated from cereals and grasses in Canada from that year up to and including 1936, with a record of the number of times each race was collected annually. The percentage that each of the seven most commonly occurring races forms of the total collections made in each of these years is diagrammatically presented in Fig. 1 B (p. 131).

From these results it is clear that, although as many as twenty-one physiologic races may be present in the fields in a single year, one or two races usually predominate. The same races may predominate for several consecutive years and then give place to different races. These in turn may be superseded by still other races. Eight such changes have occurred in Canada (Fig. 1 B). The predominating races were as follows: From 1919 to 1921, race 17; in 1922, races 17 and 21; in 1923, races 17 and 36; from 1924 to 1928, race 36; in 1929, races 36, 38, and 49; from 1930 to 1932, race 36; in 1933, races 21 and 34; and from 1934 to 1936, race 56.

During the period 1919 to 1936 a total of 94 physiologic races of wheat stem rust were isolated in Canada. Of these 50 originated from cereals and grasses in the field, and 44 from barberries in the greenhouse. The latter arose from the crossing and selfing of physiologic races.

Puccinia graminis Avenae.—Studies on physiologic specialization in oat stem rust were carried on along lines parallel to those on wheat stem rust. Up to the present ten races have been differentiated [9, 15]. The distribution year by year of these is given in Table 3 (p. 132). The proportion that each race forms of the total collections made in Canada from 1925

to 1936 is diagrammatically presented in Fig. 1 A. From Fig. 1 A and Table 3 it is clear that, since 1925, races 2 and 5 were by far the most common and widely distributed of the ten races.

TABLE 2. *Physiologic Races of* P. gr. Tritici *collected on Cereals and Grasses in Canada from 1919 to 1936, with a Record of the Number of Times each Race was collected each Year*

Races	*1919*	*1920*	*1921*	*1922*	*1923*	*1924*	*1925*	*1926*	*1927*	*1928*	*1929*	*1930*	*1931*	*1932*	*1933*	*1934*	*1935*	*1936*	*Total*
1	2	1	..	..	..	..	..	..	..	2	11	2	2	2	..	1	..	..	23
2	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	1
3	..	4	3	10	10	16	..	..	..	..	..	..	..	..	..	..	..	..	43
9	4	6	2	3	..	..	..	1	4	..	..	..	..	..	..	..	..	..	20
10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7
11	2	5	2	3	5	9	..	..	..	5	2	..	3	4	..	..	..	..	40
12	..	2	..	..	..	5	..	..	..	..	..	..	..	..	..	..	1	..	7
14	..	..	..	..	..	..	..	2	16	2	5	4	7	2	4	..	..	..	42
15	1	..	..	..	..	..	..	2	8	21	1	..	..	1	..	..	..	..	34
16	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	2
17	9	31	27	16	10	1	..	1	15	6	13	..	3	6	..	2	1	4	145
18	4	7	3	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16
19	1	..	..	..	..	..	..	1	1	6	4	1	..	17	3	..	5	4	43
21	4	..	4	24	..	1	44	84	133	103	26	22	29	15	11	20	14	7	541
23	..	..	..	..	..	..	..	..	..	4	..	..	..	..	1	..	..	..	5
24	1	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2
27	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	1
29	..	17	1	..	..	..	13	28	4	11	15	4	1	..	1	2	4	11	112
30	..	1	..	..	..	..	1	7	7	..	..	..	..	..	..	..	..	..	16
32	..	4	1	..	..	..	3	12	4	..	10	1	..	2	..	..	1	5	43
33	..	..	..	..	..	..	..	..	..	..	1	..	..	1	..	..	..	..	2
34	..	..	..	1	3	7	1	4	10	15	4	14	25	12	12	28	36	11	183
35	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	1
36	..	..	..	2	..	..	113	211	204	154	69	94	82	26	6	29	16	10	1,016
38	..	..	..	..	..	..	..	18	26	32	65	39	10	7	6	3	5	23	234
39	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	1	..	8	10
40	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1
48	..	..	..	..	..	..	..	2	..	..	2	..	..	..	..	..	..	..	4
49	..	..	..	..	..	..	..	3	8	14	68	8	17	17	4	5	..	5	149
50	..	..	..	..	..	..	..	..	4	..	6	..	4	1	2	..	..	..	17
51	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	1
52	..	..	..	..	..	..	..	1	3	6	..	..	1	..	..	..	..	..	11
53	..	..	..	..	..	..	..	..	1	..	..	..	..	1	..	..	..	..	2
56	..	..	..	..	..	..	..	..	..	..	..	..	4	10	3	42	86	147	292
63	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1
64	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1
74	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1
75	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1
77	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	1
78	..	..	..	..	..	..	..	..	..	4	..	..	..	..	..	..	..	..	4
81	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	1
83	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1
84	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1
86	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	1
87	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	1
89	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	1
97	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	1
113	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	2
123	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	1
125	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13	3	6	22
Total	28	78	44	61	29	39	175	378	450	391	306	192	195	129	53	146	172	241	3,107
Number of races collected each year																			
	9	10	9	8	5	6	6	16	17	21	20	12	18	19	11	11	11	12	

Puccinia triticina.—Many difficulties were encountered in the determination of physiologic races of leaf rust of wheat owing to the sensitiveness of this rust to changes in environmental conditions, particularly

temperature and light. Mains and Jackson [16], Waterhouse [17], Johnston and Mains [10], and Roberts [18] showed that certain physiologic

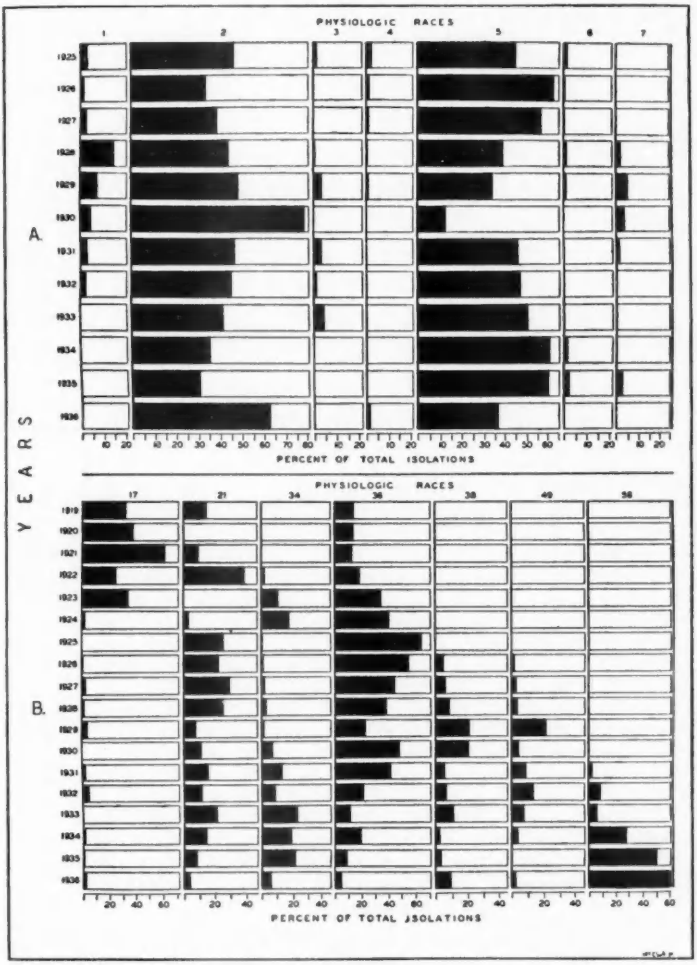

FIG. 1. Frequency of occurrence in Canada of physiologic races of stem rust, each expressed as a percentage of the total isolations made each year.

A. *P. graminis Avenae* races 1, 2, 3, 4, 5, 6, and 7, from 1925 to 1936.
B. *P. graminis Tritici* races 17, 21, 34, 36, 38, 49, and 56, from 1919 to 1936.

races of leaf rust do not produce the same reactions on certain differentials at different seasons of the year. Johnson and Newton [4] studied the effect of high temperature on the development of this rust on wheat seedlings, and found that for temperatures above the optimum for rust

development, the higher the temperature the less vigorous the pustule development. At 65° F. races 5, 35, 76, and 80 developed a '4' type of infection on wheat seedlings, above 85° F., an 'x' or a '1' type of infection, and above 90° F., chiefly necrotic flecks. Where temperature and light control are not possible in the greenhouse, the identity of many races can be established only after the culture is studied over a considerable period of time. At Winnipeg a medium light intensity and a temperature of 65° F. were found most suitable for the identification of races of this rust.

TABLE 3. *Physiologic Races of* P. gr. Avenae *collected on Cereals and Grasses in Canada from 1925 to 1936, with a record of the Number of Times each Race was collected each Year*

	Year												
Races	*1925*	*1926*	*1927*	*1928*	*1929*	*1930*	*1931*	*1932*	*1933*	*1934*	*1935*	*1936*	*Total*
1	2	3	10	41	11	4	3	2	..	..	..	..	76
2	33	79	151	120	73	65	50	49	22	26	13	43	724
3	1	..	..	1	6	..	4	1	2	..	..	..	15
4	2	3	5	1	1	..	..	..	..	..	..	1	13
5	31	144	221	105	52	10	50	52	24	45	26	25	785
6	1	1	1	2	1	..	..	..	..	1	1	..	8
7	..	..	..	5	7	3	1	..	..	..	1	..	17
8	..	..	..	..	2	..	..	5	..	2	1	..	10
9	..	..	..	..	..	1	..	..	..	..	..	..	1
10	..	..	..	..	..	..	..	..	..	..	1	..	1
Total	70	230	388	275	153	83	108	109	48	74	43	69	1,650
	Number of races collected each year												
	6	5	5	7	8	5	5	5	3	4	6	3	

During the years 1931, 1933, 1934, and 1936 a total of 140 isolations were made by Dr. T. Johnson and the writer from wheat collected in different parts of Canada, and 32 races were identified. The distribution year by year of these races is given in Table 4. It will be seen that, although races 15, 31, and 56 occurred most frequently during the period indicated, a different physiologic race predominated almost every year.

Puccinia glumarum.—Systematic annual surveys for physiologic races of stripe rust were not carried out, but from 1927 to 1935 collections from wheat, barley, and a number of grasses were studied [6]. These collections were made in British Columbia, Alberta, and Saskatchewan. Only two physiologic races, 8 and 13, were present in the material studied. Of the two races isolated, the less virulent one, race 13, was much more prevalent than race 8, being represented by seventeen of the eighteen collections studied between 1927 and 1935. Race 13 has not yet been found in Europe.

Puccinia coronata Avenae.—From 1929 to 1936 thirteen physiologic races of crown rust were collected by Peturson [12] in Canada. He found that the most prevalent of these races, namely, races 1, 2, 3, 4, and 6, occurred both in Eastern and Western Canada. Races 1 and 4

were more prevalent in Western Canada than in Eastern Canada, whilst races 3 and 6 were about equally prevalent in both areas. The distribution year by year of the thirteen races of crown rust is given in Table 5.

TABLE 4. *Physiologic Races of* Puccinia triticina *collected on Wheat in Canada from 1931 to 1936 with a Record of the Number of Times each Race was collected each Year*

	Year				
Races	*1931*	*1933*	*1934*	*1936*	*Total*
1	..	..	..	3	3
2	4	1	..	1	6
5	..	1	..	4	5
9	..	..	1	1	2
10	1	..	..	..	1
13	3	..	..	..	3
14	2	..	..	1	3
15	8	5	1	3	17
20	4	..	..	..	4
27	..	..	..	1	1
30	2	7	..	..	9
31	14	4	1	..	19
32	..	3	..	..	3
34	..	..	..	2	2
35	..	1	1	1	3
42	1	..	..	..	1
44	1	2	3	..	6
50	..	..	..	1	1
52	3	1	..	..	4
53	4	1	..	..	5
56	5	5	..	..	10
62	..	..	..	1	1
65	..	..	..	2	2
66	2	..	..	..	2
76	..	..	..	8	8
77	1	..	..	..	1
80	..	..	..	3	3
85	..	1	..	..	1
87	2	1	..	..	3
88	..	..	2	..	2
89	..	3	..	5	8
90	..	..	1	..	1
Total	57	36	10	37	140
	Number of races collected each year				
	16	14	7	15	

Puccinia anomala.—On account of the minor importance of dwarf leaf rust of barley in Canada, a yearly survey for physiologic races was not made. Brown [14] isolated four physiologic races from collections made in different parts of Canada. The relative prevalence of these races is given in Table 6. As with other cereal rusts, environmental conditions, particularly temperature, influence the reaction of barley varieties to

this rust. For instance, at 75° F., Stavropol, one of the differentials, becomes moderately susceptible to races 1 and 2, but, at 60° F., moderately resistant.

TABLE 5. *Physiologic Races of* P. coronata Avenae *collected on Cereals and Grasses in Canada from 1919 to 1936, with a Record of the Number of Times each Race was collected each Year*

Races	*1929*	*1930*	*1931*	*1932*	*1933*	*1934*	*1935*	*1936*	*Total*
1	38	24	32	28	8	14	44	12	200
2	2	22	14	24	15	15	8	11	111
3	32	52	24	18	26	10	8	15	185
4	3	5	23	20	4	20	17	9	101
5	..	..	1	..	..	..	..	4	5
6	10	13	4	4	11	..	..	1	43
9	3	..	..	..	..	..	..	..	3
10	15	..	..	..	..	..	2	..	17
24	..	1	3	2	..	1	2	2	11
36	..	..	..	..	..	..	..	1	1
38	..	..	..	..	2	..	1	1	4
39	..	..	..	..	1	..	..	..	1
C	..	..	..	..	..	..	..	1	1
Total	103	117	101	96	67	60	82	57	683
	Number of races collected each year								
	7	6	7	6	7	5	7	10	

TABLE 6. *Physiologic Races of* P. anomala *collected on Barley in Canada from 1927 to 1929, with a Record of the Number of Times each Race was collected each Year*

Races	*1927*	*1928*	*1929*	*Total*
1	4	..	..	4
2	1	2	2	5
3	..	1	..	1
4	..	..	1	1
Total	5	3	3	11
	Number of races collected each year			
	2	2	2	

Relation of Barberry to Distribution of Physiologic Races

It has been shown experimentally that stem rust is heterothallic [19, 20] and that *Tritici* races can cross freely with *Tritici* races [21, 22, 23, 24, 25, 26], and *Avenae* with *Avenae* races,[1] on the barberry. Interracial crosses within a variety of stem rust are so easily made that they probably account in no small measure for the new races of *P. graminis* that are found from time to time in the field.

[1] Unpublished data by Dr. T. Johnson and the writer.

Selfing studies of stem-rust races collected in the field indicate that many of the races are in a heterozygous condition with respect to pathogenicity, a fact that points to their origin through hybridization. Newton and Johnson [22, 23, 24, 27] selfed 14 races of wheat stem rust and 8 races of oat stem rust from the field, and found 13 of the wheat stem-rust and 4 of the oat stem-rust races to be heterozygous for pathogenicity.

Further evidence that hybridization between races occurs in the field has been shown by Stakman [28]. He and his associates made extensive surveys of races in the field and found always a proportionately larger number of physiologic races in the aecial collections than in the uredial collections. In 1935 they isolated 30 races from 178 aecial collections from the field and only 17 from 1,356 uredial collections, i.e., they found proportionately thirteen times as many races in the collections from aecia as from uredia. In Canada, a relatively small number of aecial collections from the field have been studied. Since 1927, however, a careful study has been made of the proportion of races of wheat stem rust in collections from wheat, barley, and grasses in Eastern Canada

TABLE 7. *Relative proportions of Physiologic Races of Wheat Stem Rust isolated from Cereals and Grasses in the Prairie Provinces, where barberries are rare, and the Eastern Provinces and British Columbia, where barberries are known to be present (1927–36)*

Place of origin of culture	*Total number of isolations*	*Total number of races identified*	*Ratio of number of races to number of isolations*
Prairie Provinces . .	1,843	34	1:54
Eastern Provinces and British Columbia . .	432	32	1:13

and British Columbia, where barberries are more or less common, and in the Prairie Provinces, where practically no barberries are present. The results obtained are presented in Table 7. They show that, in Eastern Canada and British Columbia, 432 isolations of stem rust of wheat were studied and 32 races identified; and that in the Prairie Provinces, 1,843 isolations were studied and 34 races identified, i.e., the proportion of races was much greater in the barberry areas than in the non-barberry area. In the former, a different race was isolated for every 13 cultures studied, and, in the latter, only one for every 54 cultures. Had the collections from Eastern Canada and British Columbia been of aecia instead of uredia, it is probable that the number of races isolated from these areas would have been considerably greater.

Crosses have also been made experimentally between varieties. For example, *Tritici* races have been crossed with *Secalis* [22, 23, 27, 29], with *Agrostidis* [22, 25, 27], and with *Avenae* races [30]. In crosses between races of different stem-rust varieties, particularly those between *Tritici* and *Agrostidis*, and between *Tritici* and *Avenae*, considerable inter-sterility was encountered and the progeny was usually very weak pathogenically. Such crosses appear to be comparatively rare in nature, as, since 1919, hybrid strains similar in pathogenicity to the *Tritici* ×

Avenae or the *Tritici* × *Agrostidis* strains have not been encountered in the field in Canada, although, from collections made in the field, 3,107 isolations of wheat stem rust and 1,650 isolations of oat stem rust have been studied.

The races collected in the field do not necessarily represent all of those that may be produced on the barberry. Reference has already been made to *Tritici* × *Agrostidis* and *Tritici* × *Avenae* strains which are weak pathogenically and have never been collected in the field. Any weak race must have less chance of survival than one lacking such disadvantages. During some studies on the inheritance of pathogenicity and other characteristics of physiologic races of *P. graminis Tritici*, Johnson and Newton [4, 7, 31], found that when races of stem rust are inbred by being selfed for several successive generations, some of them give rise to strains that are weaker than the parent strains. Other races when inbred, however, show no such weakness. Of the weak strains resulting from inbreeding which they encountered, four types may be mentioned here.

First, there were races that had a tendency to form uredia that failed, partially or entirely, to rupture the epidermis of the wheat plant and could not, therefore, liberate their spores freely. These will be referred to here as 'subepidermal' races. Races of this type were found in an F_2 generation of a cross between races 36 and 9. They also occurred as a result of the selfing of two races collected in the field namely, races 36 and 21.

Second, there were some races weakened through inbreeding that exhibited a loss of pathogenic vigour. This loss of vigour can be most easily illustrated by means of a specific example. Race 9, when originally selfed, proved homozygous for pathogenicity. The forty F_2 cultures studied were all pathogenically alike and produced a '4' type of infection on the varieties Mindum, Spelmar, and Vernal. One of the F_2 cultures was kept in culture in the greenhouse for four years with intervals of storage in a refrigerator. At the end of that period it showed no trace of contamination. It was then selfed; but, in addition to race 9, it gave rise to a number of other races. Some of these races, for example, produced an 'x' type of infection on Mindum, Spelmar, and Vernal; others, an 'x' type of infection on Mindum and Spelmar, and an '1' type on Vernal. Other peculiarities were noted. One of the cultures produced uredia that were almost entirely 'subepidermal', whilst two others produced uredia described as Mars Yellow in colour.

Third, there were races originating through selfing that showed a greater sensitivity to high temperature than races collected in the field. Six inbred races and five races from the field were tested at temperatures from 50° F. to 99° F. The inbred races failed to produce a normal '4' type of infection on susceptible wheat varieties when the mean daily temperature exceeded 80° F. Above this temperature they developed chiefly a '3', or an 'x' type of infection, or even necrotic flecks. In other words, above 80° F., these races did not attack the susceptible wheat varieties vigorously, whereas the races collected in the field did.

Fourth, some of the inbred races produced either no aecia or only a

few aecia on the barberry. The sporidia of such races readily infected the barberry, but produced pustules with relatively few pycnia and scant pycnial nectar. The intermixing of the nectar of these pustules did not usually induce them to form aecia. For example, in a F_2 culture (race 11), derived from a cross between race 9 and race 36, the nectar of 50 pustules was intermixed, but no aecia developed. In another culture (race 1), derived from the same cross, the nectar on several hundred pustules was intermixed, but in only one of these did normal aecia develop. In three other pustules rudimentary aecia with a few aeciospores were produced.

A striking abnormality occurred in two other races, namely, in a certain culture of race 36 and of race 21. The culture of race 36 lost the ability to produce aecia on the barberry and the culture of race 21 partially lost that ability. In place, however, of aecia, the cultures of both these races produced uredia and telia on the barberry [4, 31]. For example, sporidia of race 21 were used to inoculate a barberry. The nectar on the pycnial pustules resulting from these inoculations was intermixed, but only in about one-half of the pustules did aecia develop. These pustules were of normal colour. The pustules that did not produce aecia were almost white. Many of the white pustules produced no pycnia or only rudimentary ones. Approximately six weeks after the barberry was inoculated, many of the white pustules began to produce urediospores and teliospores. The urediospores were incapable of infecting the barberry, but infected wheat seedlings readily.

Although races with any one of the above-mentioned characteristics have been found fairly often in F_2, F_3, and F_4 cultures from crosses between races of stem rust, they have not been collected in the uredial stage in the field. Such races have, however, been found occasionally when field cultures were selfed. 'Subepidermal' strains were obtained from aecia that arose as a result of selfing field cultures of both race 36 and race 21; and from the latter race there was also a strain that forms scarcely any aecia. This would seem to indicate that when selfing occurs in the field very few of the weak races survive.

As has already been stated, not all the races that arise through selfing are weak. Some of them, on the contrary, seem better fitted for distribution than the races from which they sprang. An instance of this is furnished by race 48[1]. This race forms telia about a week after the uredia appear, a characteristic that tends to limit its wide distribution, for the period of urediospore liberation is extremely short. In most races, pustules continue to produce urediospores for a much longer time (in the greenhouse, for 1–4 months). When race 48 was selfed, forty-one aecial cultures were transferred to wheat. The race proved heterozygous and segregated into thirteen cultures of race 48, twelve of race 14, eleven of race 151, and five of race 152. Within each of these four races a few cultures (11 in all) possessed the parental characteristic of forming telia very early. In some of them telia appeared only after a rather prolonged uredial period. Thus, through the selfing of race 48, there was produced a race 48 that is better adapted to survival than the original race 48 in that telial formation in it is much longer delayed.

[1] Unpublished data by Dr. T. Johnson and the writer.

Control of rusts.—Measures for the control of rusts have included chiefly the eradication of barberry, the use of fungicidal dusts, and the growing of varieties that possess some degree of resistance. Since 1925, the production by plant-breeding methods of resistant varieties of cereals has been actively under way.

Barberry eradication.—In the Prairie Provinces barberries have never become naturalized. Those planted in parks and gardens in the cities, and on occasional farms, have been eradicated. In Eastern Canada and British Columbia some are present, but up to the present no exhaustive survey has been made to ascertain how numerous and how widely distributed they are. Consequently, their importance in perpetuating stem rust from year to year has not been appraised. In these areas, although cereal production is not so important as in the Prairie Provinces, there is little doubt that the eradication of the barberry is justifiable.

Use of fungicidal dusts.—A study of various fungicides showed that finely-divided sulphur dust, when applied to growing crops of wheat and oats at intervals of a few days, was capable of protecting them both from stem and leaf rusts, provided the applications were begun before the plants became infected. As a full review of this work has been published by Greaney [32], the results will not be discussed here in detail. This method, although effective, has the disadvantage that the acreage to be treated is enormous and the labour and cost relatively great. Consequently, it could only be profitably carried out either in epidemic years or in years when prices for wheat and oats were high. It can be recommended, however, for use in experimental plots, seed plots, and whenever the crop is of sufficient value to justify the expenditure.

Rust-resistant Varieties

(*a*) *Partially resistant varieties.*—Since 1916 Marquis wheat has been widely grown in Canada. Owing to its susceptibility to rust in Western Canada, some partially resistant varieties were introduced into the most severely affected areas. For example, in 1921, Kota was introduced into Manitoba and met with some favour for a few years. Owing, however, to its susceptibility to loose smut, bunt, and leaf rust, and to its poor yielding capacity, it has practically disappeared. In 1917 and 1918 the durum wheats began to be grown quite extensively in southern Manitoba and to a much less extent in south-eastern Saskatchewan. They are generally more resistant to stem rust than the bread wheats, although somewhat more susceptible to root-rots and ergot. In 1927, in 1932, and again in 1935, however, they were quite heavily attacked by stem rust. Another wheat, Ceres, a cross between Kota and Marquis, was introduced into southern Manitoba and south-eastern Saskatchewan within recent years. This variety, in addition to yielding well, is moderately resistant to stem rust, but in the epidemic year of 1935, and even in 1937, it became heavily rusted. Like Kota it is also susceptible to loose smut, bunt, and leaf rust.

(*b*) *Varieties of greater resistance.*—During the past year, two varieties of common wheat, Renown and Apex, were distributed in limited

amounts to farmers in those areas of Western Canada most severely affected by stem rust. Both these varieties are very highly resistant to stem rust. Renown was developed at the Dominion Rust Research Laboratory at Winnipeg; the latter, at the University of Saskatchewan. Renown is a selection from a cross between Reward and H-44-24. The latter parent originated from a Marquis × Yaroslav Emmer cross. Apex was derived from a cross between Marquis and an F_1 hybrid of the cross H-44-24 × Double Cross. Double Cross is a selection from a (Marquis × Iumillo) × (Marquis × Kanred) cross, developed at the University of Minnesota.

In addition to the two Canadian wheats, a third resistant variety, Thatcher, developed at the University of Minnesota, was distributed in Canada in 1936. Thatcher is one of the best selections from the (Marquis × Iumillo) × (Marquis × Kanred) cross just mentioned.

Of the oats resistant to stem rust, one variety, Vanguard, developed at the Dominion Rust Research Laboratory, was distributed in the Prairie Provinces this year. Vanguard is a selection from a cross between Banner and Hajira.

The development of a rust-resistant cereal variety, for example, of wheat, is a rather slow process, requiring from 12 to 15 years for its completion. With respect to stem rust, the varieties just mentioned may be regarded as the first fruits of that process. They are highly resistant to that rust and are of good quality. In many localities in Manitoba in 1937, the resistant varieties, Thatcher and Renown, yielded from 30 to 40 bushels per acre and graded No. 1 Northern, whereas the two commonly-grown standard varieties, Marquis and Ceres, yielded in the same localities an average of about 12 bushels per acre. Much of the grain from the two latter varieties was so shrunken by stem rust that it had to be placed in special grades owing to its light weight per bushel. The introduction of these new varieties would appear to mark a new era in grain-growing in Western Canada.

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MECHANIZATION OF THE SMALL AND MEDIUM-SIZED FARM IN GREAT BRITAIN

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WITH PLATES 6, 7

AGRICULTURE in Great Britain is now changing fairly rapidly as a result of the introduction of mechanical power; the changes apply not only to the machinery itself, but also to the method of farming.

On medium-sized farms, especially mixed farms, the use of tractors to replace horses has resulted in an increased amount of produce per unit area and per man. To obtain the full benefits from mechanization it is necessary to use specially designed implements, and to overhaul the system of farming to balance the demand for labour throughout the year, and maintain the soil fertility. This is possible only if mechanization is combined with a knowledge of the results obtained from recent research in soil physics and chemistry, plant diseases, &c.

The mixed farmer has a wider problem than the large-scale arable specialist in that he has to provide food for his stock: grass, hay, and roots are essential, with the possible addition of sugar-beet and potatoes.

Tractors were first used only for heavy operations, such as ploughing, cultivating, and pulling a binder, the remaining work being done by horses, but for these the amount of horse labour displaced by the tractor was very small. The first step towards increasing the scope of the tractor was the introduction of special hitches for the different horse-drawn implements and for carrying out several light operations at one time to make an efficient load for the tractor. Recently it has been found that better results are obtained for some operations by using machinery designed specially for tractor work, but the change-over to tractor-implements is a gradual process, the horse-drawn machinery being replaced by tractor-implements as it gets beyond repair.

Small and medium-sized farms cannot copy closely large-scale methods of mechanization, but the tractor can now carry out practically all the jobs on a farm; and the small tractor has one decided advantage over the large farm units in that it nearly always has an economic load. Generally, the small tractor should replace two pairs of horses and one man.

The tractor.—The tractor is the keystone of mechanization and a wheeled tractor of 10 to 15 drawbar horse-power is justified if it can be given 400 hours of useful work per year. The minimum size of farm on which this is obtained depends on the proportion of arable to grassland and on the amount of row crops. For the smallest combine-harvester a tractor of 19 to 20 d.h.p. is needed. It is often necessary to supplement the tractor with a certain amount of horse labour for operations such as carting off roots and various light-draught jobs. However, where a tractor is used the number of horses should be reduced to a minimum, as it is better to use the tractor for a few unprofitable operations than to have tractors and horses overlapping, which means excess capital

outlay. Tractors do not require feeding when they are not working, but it is equally important that they do not deteriorate excessively when not in use. It has been shown that, for 400 to 1,000 hours' work a year, there is very little difference in the figure for depreciation and repairs per hour, the life in years of a properly cared-for tractor depending on the number of working hours per year. Tractor design has changed little in the last few years; such factors as the weight, drawbar horse-power ratio, and the fuel consumption per B.H.P. hour will probably remain the same over the next few years, so that there is no point in replacing a tractor until the repair bill becomes excessive. This will depend on the number of hours worked.

The ideal equipment for a one-tractor farm is a tractor on pneumatic tyres with retractable strakes and a set of rimless wheels for row-crop work if required. Pneumatic tyres show to great advantage for grassland work when conditions are favourable, and for all transport operations, but they are not easy to change, and so rather than have interchangeable steel wheels and 'pneumatics', it is better to fit 'pneumatics' with retractable strakes, which make them quite as efficient as steel wheels.

The row-crop tractor is now found on farms having a large proportion of sugar-beet, potatoes, roots, &c., on areas of from 10 to 100 acres. This type of tractor is rapidly increasing in popularity in the U.S.A. and is now available in several models in England. The characteristics of the row-crop tractor are three wheels (single wheel or two narrow wheels in front) with a short turning-radius, large-diameter wheels giving increased efficiency and plenty of clearance for straddling crops, and easily adjustable wheels to suit various row-widths. The drawbar-pull is usually 8 to 10 h.p., which is more than that required for hoeing, but is sufficient to plough two furrows in fairly stiff soil. The design is not ideal, as when ploughing, steering is a little difficult on the headlands.

Hoe-frames are attached directly to the tractor, giving an effective hoeing-width of from 4½ to 9 ft. Unless the drilling of the crops has been done with a large drill or, alternatively, with extreme accuracy, the larger widths are not possible on account of damage to the plants.

Market-garden tractors.—A market-garden or two-wheeled tractor may be used for row-crop work as an alternative either to a row-crop tractor or to a standard tractor with rimless wheels. Two-wheeled tractors are available over a range of from 1½ to 6 B.H.P. They are more expensive than standard farm tractors, compared on a power basis. The small-powered ones are too light for many soils and a few of the high-powered machines are too heavy to handle comfortably for any length of time. Improvements are being made with the higher powered models and several machines have been used to advantage for row-crop cultivation and other light work. Hoeing less width at a time suits the width of drilling and the present accuracy of the drilling better than working over the greater width necessary to make an efficient load for the row-crop tractor.

Second-hand motor-cars.—The second-hand motor-car is a possible source of additional power for the farm. Cars of high horse-power can be bought cheaply in a condition satisfactory for farm work and they are used to advantage for light transport, hay-sweeping, harrowing, and

even for belt work. The last is done by raising the back axle and wheels well off the ground and taking the drive from a rear wheel whose tyre has been deflated.

Although depreciation is practically nothing, repairs are often necessary, and it is advisable to have an extra car of the same make for spare parts. It should not be overlooked that the running costs are about as great as with a tractor (i.e. about 1 gallon of petrol per hour). The cooling system is often inadequate, but a 15 to 20 gallon water-tank fitted in the radiator-circuit allows continuous work without overheating.

Ploughing and cultivating.—The uses of a tractor for ploughing and seed-bed preparation are well known. Mechanization has not brought about many changes in methods or the introduction of new implements, but there has been a tendency to couple together two or more implements for different operations. This has the advantages of lowering costs and of reducing the risks of losses from unfavourable weather.

Fertilizer distributors.—Artificial-fertilizer distributors are an essential part of modern equipment and, because of the nature of their work, probably give more trouble than any other class of machine. With most types one horse can pull a machine having an effective sowing-width of 8 or 9 ft. A small farm tractor can easily handle a distributor of 12 ft. effective width, and, with dressings of not more than 2 cwt. per acre, will sow 30 to 35 acres in a fair working day. The ordinary one-horse-width distributor is light draught for a tractor, and if a horse is not available, a more economic load is made by coupling two distributors together, or by working one machine fitted with 'pneumatics' at high speed.

A distributor recently introduced here from New Zealand (Plate 6, Fig. 1), appears likely to meet with considerable success. It may be attached to the rear of any farm lorry by means of two clamps. It has no land wheels, and takes its drive for the various components of the distributing mechanism from a sprocket attached to the hub of a rear wheel of the lorry. Fertilizer is first fed from a lorry into a short top hopper, which is divided into two containers by a central partition, and then fed by a short worm to the second hopper, which in the machine illustrated is 16 ft. wide. The top of the second hopper contains a chain-conveyer for feeding fertilizer from the top hopper to the entire length of the distributing mechanism, which is a screw-conveyor in a trough immediately below the chain-conveyor. If it is desired, the two divisions of the top hopper may be used to mix two fertilizers in various proportions. If only one fertilizer is being sown, it is fed into both divisions of the hopper. Rate of sowing is regulated by the speed of the screw-distributor, which is driven from a multiple-gear disk. The machine is simple in design, easy to clean out, has a good range of sowing rates, and works satisfactorily at lorry speeds up to 15 m.p.h.; and distribution at the higher speeds is more even than for the same design at low speeds. It is an advantage to have the fertilizer on the lorry and so avoid the usual stoppages for refilling; and although a lorry with a ton or more of fertilizer cannot be taken over arable land in all conditions, the high rate of working makes it possible to complete the work when the ground is in a fit condition.

The machine will sow calcium cyanamide evenly at the rate of 1½ cwt. per acre, covering 15 acres per hour. Calcium cyanamide, in addition to supplying a top dressing of nitrogen, is almost as effective as spraying with copper sulphate or dilute sulphuric acid for killing charlock. For an effective kill the sowing must be carried out in the few hours of the early morning when the dew is heavy. The distribution must be even enough to ensure that every plant receives at least one blob of the powder. It has been found possible to do this with the above machine working at speeds of 10 to 15 m.p.h., whereas an ordinary distributor is too slow, and its distribution is more uneven than that obtained at the high speeds with the New Zealand machine.

Row crops, sugar-beet, &c.—The mechanization of the sugar-beet crop is by no means complete. The tractor can replace horses for some of the heavy operations, but little progress has been made towards reducing the large amount of hand labour required at certain seasons. This extra labour, being costly and hard to come by, is often the deciding factor against growing sugar-beet.

The tractor used for this work is either the standard tractor with rimless wheels, or the special row-crop tractor. The most favoured type of row-crop equipment in Great Britain is that which is attached to the tractor, but carried on its own wheels directly behind the tractor, and similar in design to the steerage horse-hoe. Normally it requires two men to work it, a driver and a man controlling the hoes, but for some cultivating work the tool-frame may be locked and it is worked as a one-man outfit.

A full range of implements can be fitted to the frame, and some form of lift is operated from the tractor-driver's seat. The working width is 6 to 9 ft., but with the greater widths it is difficult to obtain the necessary strength without applying excessive weight to the rear of the tractor.

Hoeing by tractor gives advantages in speed of working, which means that hoeing can be carried out at the correct time, but not in actual cost as compared with horses. Two skilled men—one driving the tractor and the other steering the hoes—are required with the tractor-outfit. With the horse-hoe a skilled man and a boy can cover half the effective width of the tractor-hoe at nearly the same speed, and a tractor costs practically as much per hour as one horse does per day.

On several counts horse-cultivation is preferable on the medium- or small-sized farm. For instance, unless the drilling is exceptionally accurate the drill must be as wide as the working hoeing-width. Also the land must be level, with an even tilth, because, in spite of independently mounted tines, uneven tilth causes inefficient work when four or more rows are covered at a time. The correct setting of the hoes must be done carefully and takes a considerable time even with skilled labour. All things considered, there is little to be said for mechanical beet-cultivation on the small- and medium-sized farm if horses are available.

An alternative to a row-crop tractor is the medium-sized market-garden two-wheeled tractor on any except heavy land. Much of the early hoeing is very shallow and two or three rows of beet are well within the power of a 2½ to 3½ h.p. tractor.

Spacing drills have received much attention with the idea of reducing the cost of the beet crop, but they have not proved very attractive. Except for a reduction in the amount of seed required, there is practically no saving in the hand labour for singling, and the final plant-population is not quite equal to that obtained from the normal practice.

Cross-blocking, i.e. hoeing at right angles to the direction of drilling and leaving bunches of plants, enables hoeing to be done after singling in two directions and so saves much hand labour. More seed is used to avoid excessive gaps, and the cross-blocking must be done with some form of tractor, as a horse would damage the plants that are left in the bunches. The final plant-population is usually only three-quarters that obtained with good hand singling, but it is possible that, with the increasing difficulty of getting outside labour, we shall eventually reach a stage where cross-blocking in fairly narrow rows will be economical.

No mechanical harvester, i.e. a machine that will top and collect, has been found satisfactory under all the conditions likely to be met with, and when such a machine is available it will only be within the means of the man growing a large acreage of sugar-beet. A single-row lifter of the two-pronged type, or a two-row loosener attached to a tractor with rimless wheels, is generally used.

The transplanter or plant-setting machine, although it cannot be used for beet, is an excellent machine for kale, cabbage, &c., and there seems no reason why it should not become popular on farms growing 20 acres or more of these crops. In its most simple form it is an inexpensive machine: the plants are put by hand into an open furrow made by a specially shaped coulter, and press-wheels afterwards consolidate the soil that has fallen back round the plants. The operators have seats as near as possible to the ground. The usual size is a two-row machine with an operator to each row. Three men—a tractor driver and two planters—can plant 3 acres per day with a maximum of 30,000 plants per day. Except in very wet soil the work is superior to hand 'dibbling', the plant having a better opportunity of growing. The advantage is greater when the soil is very dry, and a transplanter will work when hand dibbling is impossible. The machines are particularly useful in districts where the farm men are not skilled at hand planting.

Potatoes.—The potato crop is seldom completely mechanized, but it fits into the rotation of a mixed farm where a tractor and some horses are available. Besides the deep ploughing and cultivations necessary before planting, operations such as deep cultivation between the rows just after planting are more effectively done with a tractor.

When a row-crop tractor is used instead of horses the headlands may be a yard less, which appreciably increases the amount of crop grown in a field.

At certain times the growth of the potato is so rapid that speed in cultivations is essential: this is another advantage of the tractor, and although the actual working cost is not much less than with horses, the tractor is advantageous provided horses are available to carry out the lighter work. The row-crop tractor carries an extended tool-bar behind, and the various three-row potato-equipments can be fitted as required.

The ordinary potato spinner-lifter is mostly used with two horses. Satisfactory tractor-machines with a self-lift are available and are used mainly on heavy soil, but generally the only advantage that can be claimed for the use of a tractor for lifting is that two or three horses are released for haulage of the potatoes off the ground. Actually it has been found better to keep the horses for lifting and use the tractor on 'pneumatics' for haulage.

Where horses are not available, the potato plough, used before the introduction of the spinner, and consisting of a ridging-plough fitted with lifter-bars, is more effective at the higher speeds of the tractor and is less likely to damage the potatoes than a modern tractor-drawn spinner.

The chain-elevator lifter has not proved very popular in this country because it has a high draught and breakages are more frequent than with a spinner. The modern spinner has been modified to avoid damage as far as possible, and to reduce labour costs by delivering the tubers in a narrow band instead of being scattered over a wider area. The improvements include rubber tips on the spinner tines of some machines; on others a reduction in the peripheral speed of the tines, combined with improved tine action, so as to give the same digging effect as with the higher speeds. One machine has a two-speed gear-box, so that the tine speed can be varied to suit the soil conditions and the type of soil. In most modern spinners the tubers are delivered to an auxiliary spinner with closely placed tines. The soil passes through the tines and the potatoes are dropped in a narrow band.

Efforts to produce a satisfactory combine lifter-collector are still very much undeveloped. The difficulty of dealing with the haulm can be overcome either by using a separate machine made for cutting and removing the haulm, or by spraying with sulphuric acid. The main difficulty, however, is separating stones from potatoes.

Grassland.—Much of the work necessary for grassland improvement and maintenance can be done at a time when other work is impossible, the tractor being then available for the machines too heavy for horses. Much attention has been given to this work and implements ranging from those having heavy cutting-tines to strong flexible harrows have been introduced. The more drastic machines are necessary to open up the ground and remove the dead, matted grass that follows bad grazing, and insufficient or incorrect manuring. It is essential that these machines be self-cleaning, especially when used with tractors.

For farms where the area to be treated does not justify the purchase of a specially designed machine, suitable tines for attachment to standard cultivators can be used, but in this case several operations are necessary to get the desired effect.

The use of all these implements must be combined with a dressing of fertilizer and correct after-management. Then, provided the good grasses have not completely died out or become very weak, a pasture may be improved to several times its former value, affording an increased yield, an extended growing-period, and more nutritious feeding.

Where drainage is necessary, a small tractor with a winch can pull satisfactorily a mole plough at the required depth, and as this is cheaper

and more convenient than calling in an outside contractor, the drainage can be done much more extensively.

Haymaking.—Methods of haymaking have changed with the progress in machinery and on a wide range of farms haymaking is now mechanized, but success still depends a great deal on climatic conditions. Hay-harvesting occupies only a short period of the year and the capital outlay that is justifiable must depend on the amount of hay to be made per year. But the difference between good-quality and poor-quality hay is so great that any system which improves the quality justifies some increase in capital expenditure.

The modern tendency has been to speed up the work and reduce the costs at the expense of feeding-value. Experiments on using haymaking machinery, combined with an intimate knowledge of climatic conditions, have shown that at a slightly higher expenditure hay of greatly increased quality with a shorter drying-period in the field can be obtained. Increased feeding-value is important to the farmer who grows hay for consumption on the farm, and on the small and medium-sized farm, where it is not necessary to collect hay at the highest possible speed, extra attention is well worth while.

Power-mowing is little, if any, cheaper than horse-mowing, but this being heavy work and falling at a time when all available horses are in demand for other purposes, it has advantages which are difficult to estimate in cash value.

In properly organized haymaking, the various stages should be carried out at approximately the same rate, since there is little object in using a tractor-mower cutting two acres per hour if the field staff cannot collect the hay at this rate. On the medium-sized farm the amount of mowing required does not often exceed 10 to 12 acres per day. A very useful implement for this work is the recently introduced auxiliary-engine mower. It is drawn by a single horse and the cutting mechanism is driven by a 2½ h.p. petrol-engine. In practice one horse is able to do the ordinary work of three.

Mechanical sweeps are best for collecting hay to be stacked in the field. One tractor-sweep will clear about 1½ to 2 tons per hour, but this is being superseded by the motor-car sweep, which can clear as much as the tractor-sweep per hour, and has the additional advantage of delivering the hay in smaller loads and releasing the tractor for other work.

Hay from a sweep may be stacked by elevator or stacker, or baled. Baling is a method which is becoming increasingly popular in the southern parts of England. In addition to the ram-baler (this *Journal*, 1933, **1**, 63–7), the press-baler, intrdouced from the Continent, is making rapid headway (one type is shown in Plate 6, Fig. 2). It may be described briefly as a cross between a trusser and a baler, in which the bales are tied with twine by a mechanical knotter. The machine is made in several sizes and as either a stationary or pick-up baler. The stationary model is more satisfactory except in light crops, although it requires extra labour to operate. A team of 5 men is required to work a self-tying baler, i.e. 1 sweeping, 2 feeding, 1 loading the bales on to a wagon

and 1 taking the bales to the barn and stacking. The output is 2 tons per hour, which is enough for the medium-sized farm.

The bales from a press-baler are not so compact as the wire-tied bales, but are satisfactory if the hay is for home consumption. The power-requirement is small (2½ to 5 h.p.), and it may be driven by a small engine or even by motor-car if a tractor is not available.

A baler having an output of 2 tons per hour costs approximately £200, so that unless about 200 tons of hay or hay and straw are baled each year, the capital expenditure is high. Very shortly smaller models of the ram-type and the press-balers will be available to meet the needs of the smaller farmer who would be satisfied with an output of about 1 ton an hour.

It has been found that baled hay is superior in quality to stacked hay. It can be collected at a moisture-content above that required for stacking, so that there is a saving in leaf-parts, and the final product has a better colour than stacked hay. The labour saved in winter is also considerable.

Grass-drying.—Grass-drying in its present stage does not appear attractive for the small or medium-sized farm. There is no doubt about the very high feeding-value of the product, but at present it seems better for all except the large farmers to buy concentrated foods rather than use a process which makes such high demands on capital and labour. The plant, as well as the drier, must include cover for the drier, storage sheds, and special cutting and collecting machinery. Further, unless the present average output of 2½ cwt. per hour is greatly increased, the grass-drying process cannot replace haymaking, because at the flush periods growth is too rapid for the capacity of the plant; if cutting is delayed, the final product will be a less concentrated feeding-stuff.

Corn-harvesting.—Apart from the introduction of the combine harvester-thresher, the changes in corn-harvesting machinery have been minor ones. The binder operated with power take-off has distinct advantages over the horse-drawn machine. It is more strongly constructed, being made to stand up to speeds of from 3 to 3½ m.p.h., and has a cutter-bar of 7 or 8 ft.

A properly designed sheaf-carrier on the binder halves the cost of stooking. It catches the sheaves as they are delivered and may be used to hold them until enough for a stook has been collected.

Corn-collecting with tractor and car-sweeps is not very satisfactory because of the losses through shedding. The best results are obtained by working the sweeps at high speed so that the sheaves are pushed well on to the sweep, and as many as four stooks at a time can be carried on a car-sweep. A lifting device similar to that used for hay-sweeping considerably reduces losses.

Another use for a car in the harvest-field is to push over stooks when the butts need drying. It is done by means of a projecting bar attached to the rear bumper. When using a sweep to collect sheaves on the ground it should approach them crosswise.

A machine that might help considerably with harvesting is the sheaf-loader. This is not yet on the market, but at least two farmers in different parts of the country have built one on their farms. The machine (Plate 2, Figs. 3, 4) picks up sheaves either from the stook

FIG. 1. Fertilizer distributor attached to a lorry

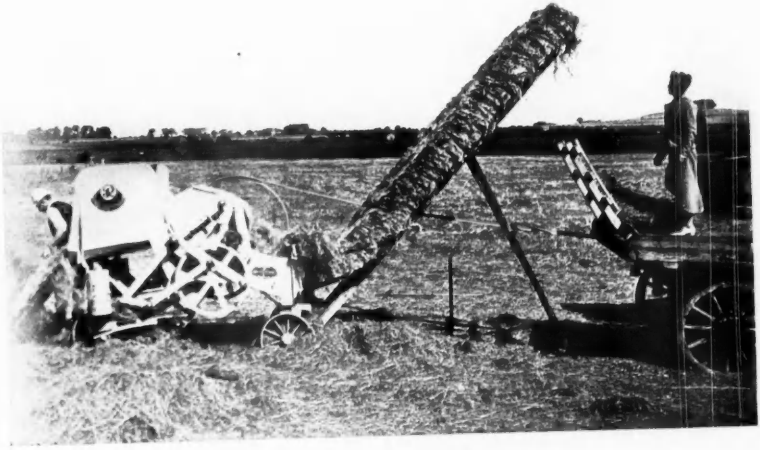

FIG. 2. Self-tying press-baler for hay

FIG. 3. Mechanical pitcher loading barley

FIG. 4. Mechanical pitcher, showing elevator

or from the ground, and conveys them up an inclined elevator and along a cross elevator into a trailer or wagon. The wagon is directly behind the tractor and the elevator is offset. The front of the elevator is carried on the front axle of a car to facilitate steering. An auxiliary 2½ h.p. petrol-engine mounted beneath the elevator drives the two elevators, and a light framework is attached to the wagon to hold the sheaves. At present two men are necessary to stack the sheaves, but a full-sized load was lifted in 10 minutes and it was estimated that there was a saving of practically two men in the field.

Combine-harvesters do not effect a very great saving in all-in harvesting costs, but they make their appeal from the point of view of labour-saving and as a safeguard against wet weather. Many methods for straw-collecting used by the large cereal farmers cause the loss of a fair proportion of the straw, owing to the long stubbles and the delays between cutting and collecting. To the mixed farmer the straw is worth between £2 and £3 per acre, and the value of the straw lost by using a combine-harvester might easily be more than the saving in all-in harvesting costs.

It is best to collect straw from a 'combine' by means of the self-tying pick-up baler, which is operated by one man on a tractor. The bales are dropped in heaps in the field. The straw baler should follow the 'combine' immediately, as straw rapidly deteriorates if left on the ground.

A drier and a storage-bin are indispensable to a 'combine'. The moisture-content of the grain varies throughout the day and a large proportion is cut in a state unfit for any form of storage without drying.

Two small 'combines' introduced during the last two years are quite different in design from the standard 'combine' introduced from the U.S.A. It seems possible that they will meet the requirements of the medium-sized farm, growing from about 100 to 150 acres of cereals. One of these machines, which costs about £250, has a 5-foot cutter-bar with a drum the full width of the cutter-bar directly behind it. The platform-canvas runs up at an angle and meets a short upper canvas. These feed direct to the drum. The straw is afterwards conveyed to a vibrating straw-rack instead of to shakers of standard design. The machine has proved that it can deal with 130 to 180 acres of average crops per season, and in a good run of 8 hours has threshed 57 quarters of wheat. It can deal with heavy bulky crops, cut close to the ground, and handle wheat, oats, barley, beans, and rye, and, what is very important from the point of view of mixed farming, damage to straw is reduced to a minimum. It is drawn by a tractor of medium size with power take-off.

The other machine is designed like a binder, with the threshing drum placed at the top of the elevator canvases. The threshed straw goes to the knotter-platform and is dropped as with the binder. This machine can also be drawn by a medium-sized tractor with power take-off.

These machines will make an increasing appeal if it is found that the life and the maintenance cost are not too unfavourable when compared with those of a power-binder.

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THE EFFECT OF IRRIGATION ON THE PALATABILITY OF CERTAIN GRASS AND CLOVER SPECIES GROWN IN PLOTS OF PURE SPECIES

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THE palatability of herbage plants has been investigated at the Welsh Plant Breeding Station for several years, and the results obtained from trials of species and strains, as well as from farm and hill-land investigations, have already been published [1, 2, 3, 4]. In June 1935 an opportunity occurred for testing whether the relative palatability of certain grass and clover species was influenced by irrigation, and an experiment was begun with this object in view.

Material and Methods

The experiment was conducted on the estate of Mr. S. M. Bligh, Cilmery Park, Breconshire, where a water-channel ran alongside a piece of permanent grass. The water was not derived entirely from one catchment area, but it was estimated that 80 per cent. came from a 'dry moor', 15 per cent. from a peaty 'wet moor', 4 per cent. from agricultural land, and the remaining 1 per cent. was spring water. Approximately an acre of land on one side of the channel was suitable for the experiment, in that half of it was on slightly higher ground than the remainder and could thus be kept free of water from the channel, whilst the remainder could be irrigated by blocking the channel and causing the water to overflow. The experimental area was at an elevation of approximately 495 ft., and the soil was a podsol derived from a heavy substratum of Silurian shale and showing a marked acid reaction.

In June the area was ploughed, a tilth obtained, and pure species of grasses and clovers sown down in 1/100-acre plots. Five Station-bred grasses, a commercial broad red clover, and a wild white clover were used. These, with the seed-rates per acre, were as follows: perennial rye-grass, pasture strain (S. 23), 25 lb.; cocksfoot, pasture-hay strain (S. 26), 25 lb.; timothy pasture strain (S. 48), extreme pasture strain (S. 50), and hay strain (S. 51), each 15 lb.; red clover, 12 lb.; and wild white clover, 12 lb. Eight replications of each species and strain were sown and arranged so that four occurred on each section.

Germination and establishment of the seeds were good throughout the area, and the first grazing was made on October 19 of the year of sowing. This was followed by seven grazings in 1936, and a final grazing in the spring of 1937. The procedure at each grazing consisted in giving marks on a scale of 0–10 for the relative growth on the plots, and then turning a flock of sheep on to the area, the number of sheep varying with the total 'keep' offering at each grazing. After the sheep had been on the plots for some hours, generally 24, marks were given for the relative amount eaten from each plot. These markings were supplemented by note-taking. The herbage which remained was then grazed off

closely, so that only fresh growth was offering at the next grazing. The irrigation-water was run over the section to be irrigated for approximately a fortnight before each grazing. This period of time varied, however, as the amount of water in the channel altered to some extent with the weather. Subsequent to sowing, the whole area received $6\frac{3}{4}$ cwt. per acre of North African phosphate.

Results

(*a*) *Growth.*—The figures for the four replications of each species and strain on the two sections of the experiment have been averaged throughout.

TABLE 1. *Relative Growth and Amount Eaten of each Species.* (*Markings on a Scale of 0–10 averaged for the Nine Grazings*)

Species	*Relative growth*		*Relative amount eaten*	
	Irrigated	*Non-irrigated*	*Irrigated*	*Non-irrigated*
Perennial rye-grass (S. 23) .	8·2	6·4	7·9	7·5
Cocksfoot (S. 26) . .	7·8	7·2	6·8	6·4
Timothy (S. 48) . .	7·4	4·8	8·7	6·0
„ (S. 50) . .	8·0	5·3	8·9	6·0
„ (S. 51) . .	8·0	5·6	9·2	7·3
Broad red clover . .	5·5	3·7	9·2	7·6
Wild white clover . .	6·6	5·4	8·9	8·0

In Table 1 are given the markings for relative growth and relative amount eaten, the figures being averages for the nine grazings. It will be seen that the growth on all plots was greater on the irrigated section than on the non-irrigated, but that the difference for cocksfoot was less pronounced than for the others. The growth at the several grazing-dates gave variations between the relative growth of the two sections for the individual grasses and clovers. Thus for three consecutive grazings in the late summer of 1936 the relative growth of cocksfoot and white clover was equal, or greater, on the non-irrigated section than on their irrigated plots, and this also applies to the perennial rye-grass on one of these grazings. The normal rainfall on the area would have had an influence upon the herbage of the two sections, but the majority of the species and strains gave greater growth under irrigation at these particular grazings.

At the final grazing, taken in the spring when 'keep' is so valuable, the growth on all plots was greater on the irrigated section, the relative figures for an average of all the species and strains being 8·7 compared with 5·7, as is indicated in Table 2, where data for relative growth and amount eaten for the individual grazings are given. This Table also shows that the average growth was consistently greater on the irrigated section for every grazing.

In regard to quality of growth, two matters call for comment: a tip-burning on two grass plots on the irrigated section, to be referred to later; and the leafage of the grasses on the non-irrigated half becoming

hard and wiry at the final spring grazing, that on the irrigated half being open and luscious.

(*b*) *Palatability*.—The data in Table 1 indicate that there was a relatively greater amount eaten of every species and strain from the irrigated section. This difference in palatability of irrigated and non-irrigated herbage, was, however, more pronounced in respect of the three strains of timothy and of the red clover than of the perennial rye-grass, cocksfoot, and white clover. When irrigation was started, in October 1935,

TABLE 2. *Average Relative Growth and Amount Eaten of the Species and Strains as a Whole for each Grazing*

		19. x. 35	*18. iv. 36*	*16. v*	*13. vi*	*14. vii*	*4. viii*	*28. viii*	*3. x*	*3. v. 37*
Relative growth	Irrigated	3·9	6·3	7·6	8·7	8·3	7·9	7·5	8·1	8·7
	Non-irrigated	2·3	3·8	4·8	6·2	6·4	6·3	6·8	6·8	5·7
Relative amount eaten	Irrigated	8·0	10·0	8·2	8·6	8·6	8·6	8·1	9·4	8·9
	Non-irrigated	7·7	10·0	6·7	6·4	6·9	7·4	6·7	7·4	6·9

it increased the relative palatability of perennial rye-grass and the strains of timothy, but decreased that of cocksfoot by making the growth too strong for the sheep; the shorter, more delayed growth of cocksfoot on the non-irrigated section was more palatable. This effect of irrigation upon cocksfoot occurred again at the grazing on July 14, but on August 28 this species was too advanced on both sections to be of good palatability. Perennial rye-grass, on the other hand, was often one of the best-grazed grasses throughout the experiment. The timothy gave a very marked response to irrigation in regard to amount eaten. At several grazings the hay strain (S. 51) was grazed to a greater extent than the other two strains. The differential grazing of strains of the same species has been previously noted [2, 3], and the data indicate that accessibility is the chief reason, the sheep eating the upright growth of the hay strain more readily than that of the pasture strains. The red and white clover plots were much frequented by the animals throughout the area, but more so on the irrigated section. It has previously been found that red-clover plots in a series of more numerous grass plots are grazed with avidity [4].

The order of palatability of the species on the two sections differed at certain grazings. Thus on July 14 timothy was the most palatable species on the irrigated section, and cocksfoot the least; whilst on the non-irrigated, perennial rye-grass and timothy (S. 51) were allotted equal marks, and cocksfoot was very little lower, but the palatability of the other strains of timothy was inferior to that of cocksfoot. The grazing on October 6 gave the most striking result. At this date the palatability of every species and strain was not only greater on the irrigated section, but irrigation had levelled up the relative palatability between the species and strains. The palatability on the non-irrigated half, on the other hand, showed the same range among the species as has been frequently observed.

Reference to Table 2 indicates that at the final grazing, taken in the spring of 1937, there was a marked difference in relative amount eaten

of the more abundant and better-quality herbage offering on the irrigated section. As stated above, the herbage on the non-irrigated plots was poor compared with that on the irrigated at this date. That there should have been such marked differences at this particular grazing is remarkable, because the winter and spring of that year were very wet and therefore the plants with no irrigation had an abundance of moisture.

Taking the two sections as a whole, and considering the average of the species and strains, Table 2 shows that the palatability of the irrigated herbage was greater throughout the grazings, with the exception of the first spring grazing in 1936. At that date the keep was scanty, with the result that the grazing was hard throughout.

(*c*) *The swards.*—The nature of the swards in the plots of the two sections was studied, and Table 3 gives the results of marking on a scale of 0–10 for density of the entire herbage on July 16, and also the number of tillers per 2½ sq. ft. observed on August 28. The figures for each species and strain are averages for the replications.

TABLE 3. *Density of the Entire Plot Herbage marked on a Scale of 0–10 in July, and Number of Tillers per 2½ sq. ft. in August 1936*

Species	*Density*		*Number of tillers*	
	Irrigated	*Non-irrigated*	*Irrigated*	*Non-irrigated*
Perennial rye-grass (S. 23)	10·0	8·8	2,090	1,730
Cocksfoot (S. 26)	9·0	9·4	1,370	1,486
Timothy (S. 48)	9·7	7·3	906	1,240
,, (S. 50)	10·0	7·8	2,000	2,100
,, (S. 51)	8·8	6·0	1,350	1,205
Broad red clover	7·0	5·3	193	154
Wild white clover	9·3	8·0	973*	866

* Estimated.

The density of the herbage in July was in favour of the irrigated section, with the exception of the cocksfoot plots. For the majority of plots the more vigorous growth of the herbage under irrigation resulted in a thicker sward. The number of tillers in August corresponded to the density for all the species except timothy (S. 48 and S. 50); in these the larger number of tillers occurred on the non-irrigated plots, although the density on these was lower than on the irrigated plots. This result was caused by the presence of *Agrostis* species in the herbage. This grass benefited by irrigation, as did the sown species, and thus raised the density on the irrigated plots of these strains of timothy above the non-irrigated, where *Agrostis* was also present. A more important point, however, is that irrigation only increased the number of tillers of some of the species and strains, for on the plots of cocksfoot and the two timothy strains mentioned above, the non-irrigated plots gave the larger numbers.

It was repeatedly observed throughout the grazings that a perennial rye-grass plot and an adjoining cocksfoot plot, situated in a slight hollow on the irrigated section, were badly tip-burned, whilst the plots of these grasses in the other three replications were quite green. There appeared

to be a stagnation of the water at this place owing to lack of slope. These tip-burned plots, however, have reduced the average figures for growth and palatability in the replications of these two grasses on the irrigated section to a somewhat lower level than would otherwise have been the case.

Discussion

The foregoing data indicate that the periodical flooding of half the experimental area had a pronounced influence upon the herbage of that section by increasing growth and the relative amount eaten of that growth, and that these advantages occurred regularly throughout the grazings.

One of the most important findings was the earlier, greater, and better-quality growth occurring under irrigation in the spring of 1937. Rawlence [5], writing on water meadows in 1931, mentions that grass in these meadows comes earlier and maintains growth later than grass grown in any other way, whilst Heddle and Ogg [6], in their work on hill pastures, state that flushing produces a fresh growth of grass, and that even in winter the grass responds to watering by producing new growth. In the present experiment it is noteworthy that although the winter and early spring months of 1936–7 were consistently wet, the irrigation-water nevertheless produced a beneficial effect. At the spring grazing of 1936, the second grazing of the experiment, irrigation had considerably increased the growth, but the previous winter had been drier (the rainfall at Aberystwyth from December 1935 to April 1936, inclusive, was 12.22 in., but for the same period a year later it was 20·75 in.). As mentioned above, the irrigation-water used in the experiment was derived from several sources, spring water being one. The beneficial results which followed indicated that it was good for the purpose. The spoiling of the herbage where the flow of water was hindered, however, shows that only sloping ground should be used. The impediment to drainage which resulted in water-logging on this area was due more to the high clay-content of the A horizon itself than to the accumulation of impermeable material in the B horizon. The winter wetness of the soil had the effect of restricting root-development to the surface horizon. Owing to this lack of root-range the moisture available to the plants during the summer months was quickly exhausted, and capillary rise was not rapid enough to repair the losses by transpiration. Rawlence (loc. cit.) also states that standing water must be avoided.

Regarding the influence of irrigation on tiller production, the shoot data given by Heddle and Ogg [7] for each species in mixed hill swards show that although the total number of tillers was increased by irrigation, certain species composing these swards were encouraged by the treatment, whilst others tended to be suppressed. They point out that as the species were growing in a mixed community they were subject to interspecific competition. In the present instance it is clear that pure species of cultivated grasses and clovers react differently to irrigation in respect of number of tillers, but that they all develop greater growth in terms of length and thickness of tiller.

The general increase in growth which occurred on the irrigated section, and the lusciousness of the leafage, showed that a larger amount of nitrogen was made available to the herbage of that section. Although no nitrogenous fertilizers were sown on the plots under discussion, it must be borne in mind that the area was a recently ploughed-up permanent pasture of reasonable fertility, and contained a certain amount of wild white clover. It would therefore appear that irrigation caused more organic nitrogen in the soil to be made available to the plants on that particular section; also irrigation may have influenced the availability of the phosphate which had been applied to the experimental area. Greenhill [8], in his study of the effect of manures and irrigation on grassland, found that there were very strong indications of an interdependence of water and of nitrogen supply in their effects upon productivity.

It is interesting to note some of the effects of irrigation on grassland in Australia, where water-supply is of such great importance. Thus Bartels [9], reporting on grazing tests on irrigated pastures in Victoria, mentions their productivity and palatability and states that one of the results from an experiment was the entire eradication of rushes from a low-lying part of the field. The difficulties of comparing directly irrigated and non-irrigated pastures in the same State have been illustrated by Morgan [10], who states that the non-irrigated pastures in irrigated districts are composed of the native species, whereas the irrigated pastures are composed of sown cultivated grasses and clovers. In regard to selective grazing by sheep, Beruldsen and Morgan [11] point out that a minor element in the herbage would be relatively more eagerly sought after for the reason of variety; and that the clovers are in general more palatable than the grasses. The factor of winter growth being encouraged by irrigation, and also the converting of a somewhat unpalatable species into a more palatable condition, are mentioned by Baron-Hay and Elliott [12], working in Western Australia. A mixture of tall fescue and white clover was grown in one of their trial irrigation-plots. The fescue was particularly vigorous during the winter months, and, although a coarse grass, it was relished by the cows. The previous work on selective grazing conducted at this Station and the findings of the present experiment are in agreement with these results.

Summary

1. Data are presented on the effect of irrigation upon the growth and relative palatability of certain grasses and clovers grown in plots of pure species.

2. Irrigation caused a uniform increase in growth and palatability of herbage throughout a series of nine grazings, but different species (especially cocksfoot) responded to different extents.

3. At the spring grazings, earlier, more abundant and better quality herbage was obtained with irrigation. A wet winter and spring did not lessen its influence.

4. The range of palatability among the species and strains on the non-irrigated section was similar to that found in previous palatability

trials with pure species, but under irrigation there was a distinct tendency for differences in palatability of the species to be minimized.

5. Irrigation increased the density of the herbage, but the species and strains reacted differently in respect to number of tillers.

6. The findings are discussed with reference to chemical and other data given by investigators working on irrigation problems.

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SOME DIFFICULTIES IN THE STATISTICAL ANALYSIS OF REPLICATED EXPERIMENTS

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1. *Introduction.*—The designs known as *randomized blocks* and the *Latin square*, first introduced by Fisher for experiments on English farm crops, have proved so successful that they are now in common use in most parts of the world. *The analysis of variance*, as the arithmetical procedure to be followed in working out the results is called, is not difficult to grasp or carry out, and practical workers with little mathematical knowledge have been able to plan and interpret their experiments successfully without recourse to expert advice.

In text-book examples of the analysis of variance, the data analysed are usually the weights of some crop, measured to three- or four-figure accuracy, and the treatment responses are usually quite small, of the order of 10–20 per cent. Experimenters often find, however, that the data they have to handle are quite different, qualitatively and quantitatively, from these. The differences which are most commonly met in practice may be grouped under three headings: (1) certain treatment differences may be of the order of several hundred per cent.; (2) the data to be analysed may take the form of whole numbers (e.g. numbers of plants in a plot or of wireworms in a sample of soil from the plot) or of percentages (e.g. the percentage of healthy plants in a plot, the percentage of potatoes standing on a riddle of a certain size); and (3) there may be a group of related figures to be analysed, instead of a single figure (e.g. the number of plants classed in each of four grades according to the severity of an attack by an insect, or the weights of saleable brussel sprouts picked on each of a number of occasions).

In these cases the experimenter is often in doubt whether the straightforward analysis of variance will apply, and if not, how to handle the data otherwise. This paper is an attempt to give, as simply as possible, advice on these questions.

It may be said at once that even with such data special methods are the exception rather than the rule. So long as treatment responses are the order of 50 per cent. or under and the standard error per plot is under 12 per cent., there can be little wrong with the use of the analysis of variance, no matter what form the data analysed may take.

2. *Discussion of an example.*—The first thing which the experimenter presumably wants to know is how to tell, from an inspection of the data to be analysed, whether the ordinary analysis of variance can be used. Before discussing this, it will be helpful to consider an example showing how and when the straightforward analysis of variance gives misleading results. Table 1 shows the results of counts of the numbers of poppies in different plots of an experiment on oats, the experiment consisting of four randomized blocks of six treatments.[1]

[1] The data are taken from a paper [1] by Bartlett, who discusses briefly their analysis. The treatments have been renumbered for convenience.

Whether he carries out the computations himself or not, the experimenter should make a point of looking at the data before analysis and judging the results by inspection. If the results of the analysis of variance do not agree with his original expectations, he should ask himself why this is so. Sometimes an inspection of the individual figures will show that treatment differences were not so consistent as he had at first supposed, and sometimes the comparison leads to the detection of errors in the analysis itself, particularly with experiments of more complicated design. Practice in the inspection of variable material is invaluable to the experimenter and will richly repay the efforts expended on it.

TABLE 1. *Numbers of Poppies in Oats*

Treatment	(1)	(2)	(3)	(4)	(5)	(6)	*Mean*
Block A . .	538	438	77	115	17	18	200·5
,, B . .	422	442	61	57	31	26	173·2
,, C . .	377	319	157	100	87	77	186·2
,, D . .	315	380	52	45	16	20	138·0
Mean	413·0	394·8	86·8	79·2	37·8	35·2	

The results of this experiment are fairly clear on inspection. Treatments (1) and (2) are much higher than any of the others; further, (3) and (4) are clearly significantly above (5) and (6), being well above them in every block. On the other hand, there is nothing to choose between the members of the three pairs (1) and (2), (3) and (4), or (5) and (6). Such an experiment, if standing by itself, need cause the experimenter no trouble, and an analysis of variance is hardly necessary. Standard errors might, however, be required for comparison or combination with a number of similar experiments. The analysis of variance is as follows:

	D.F.	*Sum of squares*	*Mean square*
Blocks . .	3	12,877	
Treatments .	5	641,024	128,205
Error . .	15	39,799	2,653
Total	23	693,700	

The standard error per plot is $\sqrt{(2{,}653)} = 51{\cdot}51$, so that the standard error of a treatment mean (4 blocks) is 25·76, and since there are 15 degrees of freedom for error, the significant difference between two treatments is

$$25{\cdot}76 \times 1{\cdot}414 \times 2{\cdot}131^{1} = 77{\cdot}6$$

The experimenter will notice with some surprise that neither (3) nor (4) is significantly above (5) or (6), though by inspection it seemed obvious that they ought to be. To discover what is wrong, the 15 degrees of freedom which make up the error must be examined further. The subdivision of error degrees of freedom in a randomized-blocks experiment is not difficult and should be familiar to every worker. The 15 degrees of freedom may be divided into 3 which are strictly appropriate to the

[1] The value of t for 15 degrees of freedom.

comparison of treatments (1) and (2), a further 3 which are the error of the comparison of the mean of (1) and (2) with the mean of (3), (4), (5), and (6), and a further 9 which refer to the comparisons of (3), (4), (5), and (6) with each other. To obtain these, first calculate

$$(1)-(2), \text{ and } 2(1)+2(2)-(3)-(4)-(5)-(6)$$

as shown in Table 2.

TABLE 2. *Partition of Error Sum of Squares*

Block	(1)−(2)	2[(1)+(2)] −[(3)+(4)+(5)+(6)]
A	−100	1725
B	+ 20	1553
C	− 58	971
D	+ 65	1257
Total	− 73	5506

Sums of squares of deviations (3 d.f.)

16,657	331,315
8,328*	27,610*

* On a single-plot basis.

Thus, for example, 1,725 = 876+1076−77−115−17−18, and is four times the difference between the mean of (1) and (2) and the mean of the other four treatments in block A. The sums of squares of deviations from the mean, shown at the foot of each column, must be divided by 2 and $2^2+2^2+1+1+1+1 = 12$ respectively [2], before putting them in the analysis of variance, which is based on the yield of a single plot. The resulting sums of squares are the figures with an asterisk in Table 2.

The remaining 9 degrees of freedom may be found by analysing the part of the experiment containing treatments (3) to (6) only, as 4 randomized blocks of 4 treatments each. This gives, on a single-plot basis, 3,861. Since

$$39{,}799 = 8{,}328+27{,}610+3{,}861,$$

this proves that the subdivision made is a correct one and at the same time checks all the arithmetic involved. Thus we have the following subdivision of the error degrees of freedom:

Comparison	*D.F.*	*Sum of squares*	*Mean square*	*Standard error*
(1)−(2) . .	3	8,328	2,776	52·7
½[(1)+(2)]−rest .	3	27,610	9,203	95·9
rest . . .	9	3,861	429	20·7

The mean squares of the two comparisons involving the first two treatments are respectively 6·47 and 21·5 times the mean square involving comparisons of treatments (3) to (6) only. Both these ratios are significant, as may be verified from the z-table or the variance-ratio table.

Thus comparisons involving the two treatments with high numbers of poppies have a higher standard error than comparisons involving treatments (3) to (6), which gave much smaller numbers of poppies. The pooling of these errors into one estimate is therefore quite unjustified and has the effect of under-estimating the standard error of some treatment comparisons and over-estimating that of others. In particular the standard error per plot appropriate to comparisons between treatments (3) to (6) appears to be 20·5, instead of 51·5 as given by a combined analysis.

At this stage we may feel that the 9 d.f. error also merits further examination, since it too is composed of the errors of a large treatment difference [(3)+(4)−(5)−(6)], and two small ones. As an exercise, the reader may divide the 9 degrees of freedom into three sets of 3 degrees of freedom as follows:

Comparison	*D.F.*	*Sum of squares*	*Mean square*	*Standard error*
(3)+(4)−(5)−(6) .	3	1536·0	512·0	22·6
(3)−(4) . .	3	2266·5	755·5	
(5)−(6) . .	3	58·5	19·5	
Total	9	3861·0		

The 5 per cent. and 1 per cent. values of the ratios of the mean squares for two sets of 3 degrees of freedom are 9·28 and 29·5 respectively, so that the errors of comparisons involving treatments (3) and (4) are significantly higher than that involving only the difference of the treatments (5) and (6). The first two mean squares are not significantly different, but considering how variable the errors in this experiment have proved, it would not be fair to combine the two. Thus for an error for the comparison of the mean (3) and (4) with that of (5) and (6), we are forced to the value 22·6, based on only 3 d.f., so that the value previously reached, 20·5, is not only too low, but based on too many degrees of freedom. With the new error, the 5 per cent. significant difference between the mean of (3) and (4) and that of (5) and (6) is found to be 36·0, and the mean difference itself is 46·5.

This example illustrates the most important condition for the application of a combined analysis of variance: ***the treatment comparisons must be such that they may all be reasonably expected to have the same variance.*** When this is not so, the error found by the analysis is a weighted mean of a number of different errors and is not really applicable to any of the treatment comparisons.

The question of differential variability may be looked at from another aspect, which is useful for detecting cases that may require special methods. An idea of the variability of a treatment in this experiment may be obtained by subtracting the smallest plot bearing that treatment from the largest. Thus for treatment (1) the difference, which may be called the *range*, is

$$538-315 = 223.$$

The ranges and the mean yields are:

Treatment

	(1)	(2)	(3)	(4)	(5)	(6)
Range . .	223	123	105	70	71	59
Mean . .	413	395	87	79	38	35

The range for each treatment shows quite a close relation to the mean, increasing as the mean increases. This relation of the range to the mean is a warning that a combined analysis of variance is not justified; conversely, if the range shows no relation to the mean, a combined analysis is usually quite correct, though exceptions to this rule occasionally occur. The use of range in this respect is only satisfactory where treatment differences are large compared with block differences, as in this experiment, or where block differences are large compared with treatment differences.

3. *Types of data which may require special treatment.*—The theoretical conditions for the application of the analysis of variance are that the experimental errors to which the data are subject shall be independently and normally distributed with the same variance. Of these restrictions the last is the most important, as illustrated by the preceding example. Indeed, as every experimenter knows, the analysis of variance is widely used in practice without any guarantee that the data are strictly normal in distribution.

With certain types of non-normal data, however, there are theoretical reasons for expecting that the standard error of a treatment yield will depend on the mean value of the treatment yield. Thus different treatments (assuming that their means differ) will have different variances, and the pooling of the errors which is implicit in the simple analysis of variance is unjustified. The most important examples of this class will be discussed later. Their common feature is that the experimental errors are markedly *skew* in distribution.

The advantage of pooling the errors is that the resultant error is more accurately determined and shows itself in every use to which the results of the experiment may be put. For instance, in the result of the last section, the value of t for 15 d.f. (the original error) is 2·131, as against 3·182 for 3 d.f., so that a treatment difference must be one and a half times as large in the second case to be detected at the same level of significance. Thus there is a real loss in splitting the combined error, and with markedly skew data the principal method of attack is to transform them at once to a scale on which the data are sufficiently normal that a combined analysis may be made.

The cases in which the experimenter must think twice before going ahead with an analysis may be divided into two types: (1) Material in which there is no particular reason to suspect violent skewness or departure from normality, but where, in a particular experiment, the treatments appear on inspection to have different variances. These cases include, generally speaking, all crop yields and all whole-number counts

which are over 100 on every plot. (2) Material in which there are theoretical grounds for suspecting non-normality and a consequent relation between the standard error and the mean. This type includes small whole numbers and percentages based on small numbers, and also occurs occasionally in new investigations.

The first type should be noted by examination of the yields before analysis. No hard and fast rules can be given, but a combined analysis should not be used when some treatment differences are much larger than others. There is no reason to suppose that the variations caused in plots carrying a 30-cwt. crop of wheat grain by fertility differences, bird damage, lodging, variations in seeding and germination, &c., will be of the same size as those on plots carrying a 10-cwt. crop, and if most of the treatments in an experiment give yields varying round 25–35 cwt., but one or two vary round 8–12 cwt., not only are differences between the sets clearly significant, but we have no grounds for using the variations in one set as part of the estimate of the standard error of the other set. A common example of this type is when there is a partial failure of one or two treatments.

It is important that with such cases the experimenter should have an *objective* rule to decide when to do a combined analysis and when to omit some treatments, because there is no certainty that the omission of some treatments will reduce the apparent standard error of the comparisons in which he is most interested, and in the absence of an objective rule there is a temptation to take whichever method gives the lower error. A rule which appears to work successfully for routine analysis on English farm crops is to omit from the main analysis treatments which yield consistently more than double or less than half the main group of treatments.

Sometimes, of course, the treatment variances may be different even when their mean yields do not differ greatly. It is here that inspection of the data before analysis is useful. As an example, consider a liming experiment on mangolds grown on acid soil. The treatments consisted of three levels of two types of lime—limestone and chalk—with two controls, applied in four randomized blocks of eight plots each. The plant numbers are shown in Table 3.

TABLE 3. *Mangolds, Plant Numbers*

	Control		*Chalk*			*Limestone*			
Block	0	0	1	2	3	1	2	3	*Total*
I	140	49	98	135	117	81	147	130	897
II	142	37	132	151	137	129	131	112	971
III	36	114	130	143	137	135	103	130	928
IV	129	125	153	146	143	104	147	121	1068
Total	447	325	513	575	534	449	528	493	
Range	106	88	55	16	26	54	44	18	

Here the plant numbers on some of the control plots are as good as those given by the best treatments, but the controls are much more

variable than the treated plots, owing to partial failures on some of the former—a common effect of acidity. The same effect is also apparent, to a smaller extent, on the single dressings. It is already clear that the liming has counteracted one of the harmful effects of acidity, and in examining the further questions of the optimum dressing to apply and the relative effectiveness of chalk and limestone, the controls are best left out. The reader may verify that the standard error per plot is reduced from 28·5 to 17·1 by the omission of the controls. The question whether the standard error is reduced or increased is, however, beside the point, since the aim of the analysis of variance is to obtain, not the lowest possible apparent error, but the most accurate estimate of the actual errors to which the treatment comparisons are subject.

As regards the general treatment of such cases, there are several possibilities. (1) Sometimes unequal variability is caused by a comparative failure of one or two plots, which may be traced on inquiry to damage or error which was not in any way caused by the treatments on these plots and which the other plots completely escaped. In these cases new yields may be substituted on these plots by methods described by Yates [3], and the complete analysis may then be carried out. The reader is advised to study Yates's paper in detail, as the missing plot technique is a valuable weapon and its correct use requires much discretion. (2) Often the analysis can be carried out by omitting one or more treatments (or blocks) from the main analysis, as suggested in the last example. With randomized blocks this causes no computational difficulties. With Latin squares one treatment (or one row or column), or one treatment and one row or column, or one row and one column may be omitted without complicating the work much. The alterations required in the analysis are described by Yates [4], who gives two worked examples, one with a treatment missing and one with a column and a treatment missing, which the reader is recommended to work out for himself.

If two treatments (or rows or columns) of a Latin square have to be omitted or are missing, the exact analysis is rather complicated. There is an approximate solution which is not difficult to carry out and gives good results; but in my experience the Latin square with two treatments missing is too rare to merit its inclusion here.

In the next section methods will be developed for making a combined analysis by first transforming the data to a scale in which the variances of the different treatments are approximately equal. These methods should not be used with the type of data we have been considering in this section. The function of the transformation is to turn skew distributions into distributions which are approximately normal with the same variance. The present type of data is, however, as a rule normally distributed in the original scale (though perhaps with different variances), and although an empirical transformation might be found which apparently equalized the variances, the transformed data would probably be skew.

Finally, the standard error per plot as a percentage of the mean yield (sometimes called the *coefficient of variation*) may be noted. Where a number of experiments on the same crop are made, the experimenter

soon learns the limits of accuracy which are to be expected. This encourages him to look for improvements in the technique if the standard of accuracy attained is not satisfactory, and it also facilitates the detection of bad sites, careless field-work, and copying or arithmetical errors.

4. *Small whole numbers.*—There are two common distributions involving whole numbers—the *binomial* and the *Poisson*. The reader who is unacquainted with these should read §§ 15–19 of Fisher's *Statistical Methods*. If all plants in a field had an equal chance (say 1 in 5) of being infected with a certain disease, and we divided the field into plots each containing twenty plants and counted the total numbers of diseased plants in each plot, these numbers would follow a binomial distribution. The distribution of a *percentage* is therefore obtained directly from the binomial distribution. The Poisson distribution is also a special case of the binomial—when the chance of the event in question is very small, but we survey the result of a large number of trials.

The properties of these distributions which concern us are that they are both skew (except the binomial for an even chance) and that there is a known relation between the standard error and the mean.

For a binomial distribution with plots of n units, in each of which the chance of the feature which we are counting (e.g. disease) is p, the standard error of a plot total x is

$$\sqrt{\{np(1-p)\}}$$

The standard error of the observed *percentage* $\frac{100x}{n}$ of diseased plants in a plot is

$$\frac{100}{n}\sqrt{\{np(1-p)\}} = \sqrt{\left\{\frac{P(100-P)}{n}\right\}},$$

where $P = 100p$ is the true percentage of diseased plants. In both these cases the standard error is greatest at 50 per cent., about which value it is symmetrical, decreasing to zero at 0 or 100 per cent. For a Poisson distribution with mean m the standard is $\sqrt{m}$. Thus if the treatments in an experiment produce differences in the values of p and m, they have different variances.

Tests of significance for the Poisson and binomial series are given in *Statistical Methods* (§§ 16–19), by calculating a value which may be looked up in the χ^2 Table. These tests apply to conditions which are much more uniform than those in replicated field trials, and should not be used here. They require, for instance, that the chance of a plant being diseased shall be the same in all replicates of a given treatment, and thus take no account of differences in the incidence of disease on different plots. In fact, the variance with small whole numbers may be divided into two components, one being the variation of the binomial or Poisson type and the other the usual plot-to-plot variation.

With yield data and counts running into three figures per plot, a standard error per plot of 12 per cent. or under is commonly attained. With small whole numbers, however, consideration of the binomial or Poisson variation alone shows that this standard of accuracy is not to be expected. For the binomial series the standard error of a plot total x

is $\sqrt{\{np(1-p)\}}$, and the mean value of x is $np = m$ (say). Thus the standard error per cent. per plot is

$$\frac{100\sqrt{\{np(1-p)\}}}{np} = 100\sqrt{\left(\frac{1-p}{m}\right)}.$$

This figure also applies of course to fractions and percentages. The value for the Poisson series with a mean plot total m is similarly found to be $100/\sqrt{m}$. For plot totals of the order of 20, 10, and 5 the standard errors per plot are thus of the order of 22, 31, and 44 per cent., plus a component due to inter-plot variation. It follows that with small whole numbers, treatment differences have to be large before they have a chance of being significant, and, of course, the larger the treatment differences the more unequal their variances are likely to be. Thus with small whole numbers we cannot take the line used in previous sections, that if treatment differences are large they are bound to be clearly significant.

5. *Transformations.*—With a distribution in which the relation between the variance and the mean is known, a transformation can always be found to a new scale in which the variance is, to a first approximation, independent of the mean. The three transformations which have been found most useful in practice are shown in Table 4.

TABLE 4. *Transformations*

Distribution	*Data*	*Relation between variance and mean*	*Transformation*	*Variance in new scale*
Poisson	small whole numbers (x)	$V = x$	$\sqrt{x}$	$\frac{1}{4}$
Binomial	fractions (p)	$V = p(1-p)/n$	$\sin^{-1}\sqrt{p}$	$821/n$
	percentages (P)	$V = P(100-P)/n$	$\sin^{-1}\sqrt{(P/100)}$	$821/n$
	numbers (x)	$V = \lambda x^2$	$\log_{10} x$	$0{\cdot}189\lambda$

The relation between the variance and the mean for the Poisson and binomial distributions has already been discussed. For data of the Poisson type, the transformation suggested is to carry out the analysis on the *square roots* of the original data. A table of square roots will be found in almost every book of four-figure tables. The transformation to be used with fractions or percentages is called the *inverse sine* and looks much more complicated; we use the angle (between 0° and 90°) whose sine is the square root of the fraction. In fact, however, once a table has been prepared, this transformation is just as easy to use as the square-root one. A table will be found in Fisher and Yates's Tables [5]. The values can also be read off directly on any slide-rule which has a sine scale on the back, by setting the sine scale in position at the front. To transform 20·4 per cent., place the slide at 20·4 on the upper (square) scale and the value in degrees is read off at once as 26·9 on the sine scale.

The third type of data shown in the Table arises when the errors to which any plot-'yield' is subject are proportional to the value of the 'yield'. In this case the analysis is performed on the logs. of the original data.

The last column of the Table shows the theoretical values of the

variance in the new units. These figures are not of any great practical importance, because other sources of variation tend to increase the variance in an actual experiment. With data of a descriptive or qualitative nature, however, the observer who is scoring the plots may be influenced, perhaps unconsciously, if he knows the treatments, and this is sometimes detected by noticing that the errors are consistently lower than their theoretical values.

The way in which the transformations are derived is not difficult to follow and will be exemplified for the square-root transformation. If m is the mean value of x and $\epsilon = x - m$ is the error of x, then

$$\sqrt{x} = \sqrt{(m+\epsilon)} = \sqrt{m}\,\sqrt{(1+\epsilon/m)}$$
$$= \sqrt{m}(1+\epsilon/2m), \qquad (1)$$

approximately, if ϵ is small compared with m.

For instance, if $m = 9$, $\epsilon = 1$, the left-hand side is $\sqrt{10} = 3{\cdot}162$ and the right-hand side is $3(1+\frac{1}{18}) = 3{\cdot}167$.

Thus
$$\sqrt{x} = \sqrt{m} + \epsilon/2\sqrt{m}. \qquad (2)$$

Since the mean of ϵ is zero, it follows that, to a first approximation, the mean value of $\sqrt{x}$ is $\sqrt{m}$. The variance of $\sqrt{x}$ is by definition the mean value of $(\sqrt{x}-\sqrt{m})^2$, and from equation (2) is equal to

$$\text{Mean } \epsilon^2/4m = \frac{\text{Variance of } x}{4m}.$$

Thus if the variance of x is m (as it is for the Poisson series), the variance of $\sqrt{x}$ is independent of m and is $\frac{1}{4}$.

The reader with an elementary knowledge of the integral calculus can verify from this example that, in general, if the variance of x is $f(m)$, the transformation which equalizes the variance is the integral of $1/\sqrt{\{f(x)\}}$. The condition under which the transformation holds is that the standard error of x must be small compared with the mean value of x.

For the Poisson distribution, the ratio of the standard error to the mean is $1/\sqrt{m}$, which is too large for the conditions of the transformation when m is below 10. Bartlett [1] has shown that with m below 10 the square-root transformation tends to over-correct, so that the treatments with the smallest means have the largest ranges in square roots. He has shown that by adding $\frac{1}{2}$ to each observation before taking the square root, the variances are much better equalized, and with experiments in which the majority of the numbers are below 10, this transformation should be used instead of the simple square roots.

For individual experiments, in my own experience, the inverse-sine transformation is rarely needed. The relation between the variance and the mean for percentages is shown below (the variance is symmetrical about 50 per cent.):

TABLE 5.

Percentage	1	5	10	20	30	40	50	60	70	80	90
$\frac{n \text{ Variance}}{100}$	1	4·8	9	16	21	24	25	24	21	16	9

For percentages between 0 and 20, the variance increases roughly as the mean, so that a square-root transformation can be used. For percentages between 30 and 70, on the other hand, the variance is more or less independent of the mean, so that the analysis can be performed on the original data without transformation. For percentages between 80 and 100, the square root of $(100-P)$ may be used. Most experiments with percentages can be dealt with by one of these methods if desired. If, however, experiments involving percentages are regularly met with, or with a group of experiments on the same point, it is worth having a uniform method of analysis, and the inverse-sine transformation should be used throughout.

These methods are only necessary with percentages in which the *numerators* are under 100; with numerators over 100 a direct analysis can usually be made. With numerators between 50 and 100 per plot the case is more doubtful, but a direct analysis can often be made, provided that treatment and block differences are not large and that there is no clear correlation between the range and the mean.

Numerical examples of the uses of the three transformations are given in the next three sections.

6. *The square-root transformation.*—The plan below shows the results of an experiment with a 5×5 Latin square, the treatments being a control (0) and four different soil fumigations applied in the previous year [6]. The data shown directly under the treatment symbols are the total numbers of wireworms in four samples per plot. The 'yields' are, with one exception, all under 10, so that the $\sqrt{(x+\frac{1}{2})}$ transformation is appropriate. The actual square roots are, however, given for comparison in the second line of figures, and the square roots of $(x+\frac{1}{2})$ in the third line.

TABLE 6. *Plan and Numbers of Wireworms*

P	*O*	*N*	*K*	*M*
3*	2	5	1	4
1·73†	1·41	2·24	1·00	2·00
1·87‡	1·58	2·34	1·22	2·12
M	*K*	*O*	*N*	*P*
6	0	6	4	4
2·45	0·00	2·45	2·00	2·00
2·55	0·71	2·55	2·12	2·12
O	*M*	*K*	*P*	*N*
4	9	1	6	5
2·00	3·00	1·00	2·45	2·24
2·12	3·08	1·22	2·55	2·34
N	*P*	*M*	*O*	*K*
17	8	8	9	0
4·12	2·83	2·83	3·00	0·00
4·18	2·92	2·92	3·08	0·71
K	*N*	*P*	*M*	*O*
4	4	2	4	8
2·00	2·00	1·41	2·00	2·83
2·12	2·12	1·58	2·12	2·92

* Number of wireworms (x). † $\sqrt{x}$. ‡ $\sqrt{(x+\frac{1}{2})}$.

The treatment totals and the ranges in each set of units are shown below:

Scale		*K*	*P*	*O*	*M*	*N*	*S.E.*
Original x .	Total	6	23	29	31	35	
	Range	4	6	7	5	13	
$\sqrt{x}$ . .	Total	4·00	10·42	11·69	12·28	12·60	
	Range	2·00	1·42	1·59	1·00	2·12	
$\sqrt{(x+\frac{1}{2})}$.	Total	5·98	11·04	12·25	12·79	13·10	±1·36
	Range	1·41	1·34	1·50	0·96	2·06	

The correlation between the range and the mean is clearly seen in the original data. The tendency of square roots to over-correct with such small numbers is also apparent, as the range of *K* is now larger than that of the next three treatments in order of increasing means, and indeed is only less than that of *N* because the latter contained one value, 17, which was double the number on any other plot on the field. The analysis of variance of $\sqrt{(x+\frac{1}{2})}$ is as follows:

	D.F.	*S.S.*	*M.S.*
Rows . . .	4	2·4812	
Columns . .	4	0·9026	
Treatments . .	4	6·8747	1·7187
Error . . .	12	4·4551	0·3712

The mean-square error is not greatly above the theoretical value 0·25. The standard error is 0·609, so that the standard error of a treatment total is 1·36. The reduction in wireworm numbers due to *K* is clearly significant, but there are no other treatment effects. All tests of significance of treatment differences must be made in the transformed scale, using the standard error, 1·36.

In presenting a summary of the results of this experiment, the data should first be re-converted to actual numbers, since it is the numbers themselves in which we are interested. The transformation is made by squaring each treatment *mean* per plot and subtracting one-half. The numbers are:

Treatment Means per Plot

K	*P*	*O*	*M*	*N*
0·94	4·38	5·50	6·04	6·36

The values are slightly lower than those obtained by taking the means of the original numbers; this is a property of transformations of the square-root type. In presenting these means, it should be stated that no single standard error can be applied to them, but that the standard error of $\sqrt{(x+\frac{1}{2})}$ is 0·272. This is important, because a reader of the report may wish to use the figures for a comparison quite different from those in which the experimenter himself was interested and must be given sufficient data to do so. One of the most valuable features of the

modern replicated experiment is that the information it provides is objective and open to all, and summaries of results should be presented with this fact in mind.

7. *The inverse-sine transformation.*—The data in Table 7 are the results of an experiment with 5×5 randomized blocks on the control of virus infection of the hyoscyamus plant, which is grown for the manufacture of pharmaceutical preparations [7]. The treatments were a control (A) and different times of spraying. The plants were graded into three classes: clean, moderately infected, and severely infected.

TABLE 7. *Hyoscyamus: Healthy and Infected Plants.*

Treatments		*Blocks*					*Total*
		I	*II*	*III*	*IV*	*V*	
A	No. of plants	147	128	170	143	149	
	Moderate infection	19	30	28	17	4	
	'Severe' infection	11	5	2	5	7	
	Per cent. infection	20·4	27·3	17·7	15·4	7·4	88·2
	Degrees	26·9	31·5	24·9	23·1	15·7	122·1
B	No. of plants	140	127	156	158	201	
	Moderate infection	30	25	23	10	4	
	'Severe' infection	2	1	4	4	6	
	Per cent. infection	22·9	20·5	17·3	8·9	5·0	74·6
	Degrees	28·6	27·0	24·6	17·4	12 9	110·5
C	No. of plants	140	186	135	107	216	
	Moderate infection	20	20	19	15	3	
	'Severe' infection	6	4	0	3	10	
	Per cent. infection	18·6	12·9	14·1	16·8	6·0	68·4
	Degrees	25·5	21·0	22·1	24·2	14·2	107·0
D	No. of plants	148	142	158	126	147	
	Moderate infection	21	18	11	13	10	
	'Severe' infection	5	7	6	1	0	
	Per cent. infection	17·6	17·6	10·8	11·1	6·8	63·9
	Degrees	24·8	24·8	19·2	19·5	15·1	103·4
E	No. of plants	130	136	202	147	109	
	Moderate infection	16	0	13	14	2	
	'Severe' infection	0	6	6	2	0	
	Per cent. infection	12·3	4·4	9·4	10·9	1·8	38·8
	Degrees	20·5	12·1	17·9	19·3	7·6	77·4
	Total per cent. infection	91·8	82·7	69·3	63·1	27·0	333·9
	Total degrees	126·3	116·4	108·7	103·5	65·5	520·4

Two of the figures given in [7], Table IV, were in error and have been corrected in the above Table.

Consider first the percentage of infected plants (shown in the fourth row of the Table for each plot). These percentages are based on numerators of about 20 per plot, which is sufficiently small for a transformation to be advisable. The percentages are nearly all under 20, so that a square-root transformation could be used; the data will, however, be taken as a numerical example of the use of the inverse sine. The transformation to degrees was made by Fisher and Yates's table [5], proportional parts

being used mentally for the decimal place. The analysis of variance in degrees is:

	D.F.	*S.S.*	*M.S.*
Blocks . . .	4	431·12	..
Treatments . .	4	217·35	54·34
Error . . .	16	147·38	9·21

The summary of results in degrees and in percentages is shown below.

TABLE 8. *Summary of Results*

	Treatment					
	A	*B*	*C*	*D*	*E*	*S.E.*
Degrees . . .	24·4	22·1	21·4	20·7	15·5	±1·36
Percentages . . .	17·0	14·1	13·3	12·5	7·2	

The percentages are obtained by transferring back from degrees, using the same table or a slide-rule. For instance, to transform *D* (20·7°) by the table, we note that the readings for 12 per cent. and 13 per cent. are 20·3° and 21·1° respectively. Thus $20{\cdot}7° = (12+\frac{4}{8})$ per cent. = 12·5 per cent.

All spraying treatments have reduced the percentage of diseased plants, and treatment *E*, which was the most intensive spraying, has proved significantly better than any of the other treatments. The field results in Table 7 also give the numbers of moderately and severely infected plants. This raises the general question of the analysis of graded data. If a single index of the effect of the treatments is required, the cash value of the plot-yield has an immediate interest if it can be obtained, as is generally the case with data which are graded for the market. Where the cash value is not obtainable, a single index which is quite effective in practice may be obtained by assigning conventional scores on common-sense grounds to the various grades. With the present data we might, for instance, assign a score of 3 to a healthy plant, 1 to a moderately diseased plant, and 0 to a severely diseased plant. The 'value' of the first plot is then $3(117)+19 = 370$.

Where experiments are carried out for the increase of knowledge and not principally for the immediate commercial interest, the experimenter should know beforehand what sort of information he expects to derive from any set of observations which he decides to make. The position of the experimenter who has amassed a pile of field data and is somewhat embarrassed to know what to do with them is not one to be commended. With the type of data in the present example, the information might be divided into three parts:

1. The total plant-number (in this particular case the treatments were applied too late to have any possible effect).
2. The percentage of diseased plants, which has been analysed.
3. The severity of the disease, which might be measured by assigning a score of +1 to a plant moderately diseased and −1 to a plant severely diseased.

The mean score for plot 1 is $(19-11)/30 = +0{\cdot}267$.[1] These data could also be analysed. It is, however, clear on inspection that the treatments have had no effect on severity of disease. With diseased plants in three or four grades, convenient scores are 1, 0, −1, and 3, 1, −1, −3, respectively.

The above division is a useful one from which to summarize the results. The three factors do not, however, contain the whole of the information unless they are independent. With sugar-beet, for instance, there is commonly a negative correlation between yield of roots and sugar percentage, so that the standard errors of the total *weight* of sugar (their product) cannot be obtained from individual analyses of the roots and sugar percentage, but demands a knowledge of their covariance.

8. *The logarithmic transformation.*—The transformation to logs. equalizes the variance when it is proportional to the square of the mean; it is thus a much more powerful transformation than the square root or the inverse sine. An important case of this type of variation occurs when we are assessing the effect of a treatment on the *consistency* of the experimental material, as measured by the range or standard deviation of the material within a plot. An example of the use of logs. in this connexion, with full numerical working, is given in [8].

The log. transformation also proves useful in dealing with new material of unknown distribution. A good example occurs in an experiment on the times which a person takes to respond to each of a list of words read out to him. A list of 100 words was divided into four groups (A, B, C, D) of 25 words and each group was read out in random order to the subject. This was repeated for six sittings. Table 9 shows in descending order the total time taken to respond to 25 words at each sitting and the sum of squares of the deviations of these 25 times from their mean. The distribution of the reaction times is a very skew one, as the relation between the sum of squares and the mean indicates. The third line of the table shows the ratio of the square root of the sum of squares to the mean. The ratios are much less variable and show little relation to the means. Thus the standard errors of the original data are proportional to the means, and a logarithmic transformation is suggested.

The principal objection to transformations—that we are really interested in the original and not the transformed data—scarcely applies here, because there is nothing fundamental about the reaction times themselves; the observer might, for instance, with equal validity have measured the rates of reaction.

Logarithms may also be of use with whole-number data which cover a wide range. An example of this occurred in the analysis of the number of insects caught in a light-trap on different nights. Here the catches varied from 0 to 72,000 per night, and the resulting distribution for any species was markedly skew. The log. transformation cannot be used directly for zero values, and indeed with such a wide range the

[1] Notice that this score, being a measure of the severity, and not of the amount, of disease, is unaltered if the numbers of moderately and severely diseased plants are halved by a treatment.

transformation wanted was one which acted like the square-root transformation for small numbers, but like the log. transformation for large numbers. Such a transformation may be found by adding 1 to each number before taking the log. This behaves like the square root for numbers up to 10 and thereafter approaches the direct log.

A further justification of the use of logs. in this case is that the effects of weather factors such as temperature, amount of cloud, &c., may be presumed to be proportional to the number of insects and hence additive on a log. scale. A discussion of this example is given by Williams [9].

TABLE 9. *Reaction Times*

Sittings	*Sets of 25 words*			
	A	B	C	D
I	435*	523	349	481
	1,640†	3,350	1,089	2,223
	0·093‡	0·111	0·095	0·098
II	226	310	220	301
	415	908	438	809
	0·090	0·097	0·095	0·094
III	275	292	311	257
	684	789	1,100	651
	0·095	0·096	0·107	0·099
IV	207	204	228	223
	377	329	479	398
	0·094	0·089	0·096	0·089
V	188	214	202	283
	194	212	296	823
	0·074	0·068	0·085	0·101
VI	209	263	201	282
	354	646	321	915
	0·090	0·097	0·089	0·107

Whately Caington's data.

* Total time $S(x)$. † Sum of squares of deviations $S(x-\bar{x})^2$.
‡ $\sqrt{\{S(x-\bar{x})^2\}/S(x)}$.

9. *The use of transformations in factorial experiments.*—The advantages of combining several different factors in the same experiment have been pointed out many times [2, § 1 a]. In addition to giving full information on the effects of the different factors, the experiments also enable us to test whether the factors are acting independently of each other. In agricultural field trials, the factors are usually taken to be independent when their effects are additive in the scale in which the data are measured; for instance, in an experiment on wheat involving sulphate of ammonia and potash, a consistent increase of say 5 cwt. per acre to sulphate of ammonia at all levels of potash is taken to indicate absence of interaction. This definition has great practical convenience, since interactions can easily be isolated and tested in an analysis of variance. It would, however, probably be more natural to regard sulphate of ammonia and potash as acting independently if sulphate of ammonia produced the

same *percentage* increase at all levels of potash; that is, to regard the main effects as independent when they are additive on a log. scale. This was pointed out in 1923, in the earliest paper dealing with the analysis of a factorial experiment, by Fisher and Mackenzie [10], who also showed how to test the significance of the interaction on this definition. This test is, however, more complicated than the usual test. Further, the two definitions differ little unless the responses to both factors are large, as the reader may verify by constructing a few examples showing absence of interaction on the two scales. For these reasons the first definition given above is the one which has been commonly used in practice.

With the types of data for which the transformations have to be used, however, it has been shown that treatment differences generally have to be large to be significant. When this is so, different definitions of interactions cannot be regarded as roughly equivalent. The experimenter must decide for himself what is the most natural definition of the independence of two factors, and if necessary treat the test of an interaction as a separate problem. The following example illustrates this point. Table 10[1] shows part of the results of a factorial experiment on the transmission of a virus disease of tobacco by an insect. The treatments are all combinations of different lengths of starvation periods of the transmitting insects, before and after access to an infected plant. The data are the numbers of diseased plants out of 50 and are the totals of ten replications.

TABLE 10. *Numbers of Diseased Plants (out of 50)*

Preliminary starving	*Post-infection starving*			*Total*	*Rate of fall*	*0 min.—1 hour*	
	0	*15 min.*	*1 hour*			*Original units*	*Degrees*
0 . .	6	2	1	9	1·67	5	12·2
15 min. . .	18	11	6	35	1·03	12	16·6
1 hour . .	27	15	7	49	1·22	20	25·3
6 hours .	32	22	9	63	1·10	23	28·0
Total	83	50	23				

It is clear that the transmission of the disease increases as the preliminary starving-time is increased, and decreases as the starving-time after access to an infected plant is increased. The natural way in which to interpret interaction in this case is to regard these factors as acting independently if the percentage rate of fall from 0 to 1 hour's post-infection starving is the same for all times of preliminary starving. This rate of fall is probably best measured by the ratio of the fall from 0 to 1 hour to the mean of the three values 0, 15 min., and 1 hour. These ratios are given in the Table. There is little indication of an interaction, except possibly that the rate of fall may be higher with no preliminary starving, though this value is subject to a large error on account of the small numbers involved.

The conventional interaction-term in the original scale is the comparison of the four differences between the values for 0 and 1 hour's

[1] M. A. Watson's data, to be published shortly.

post-infection starving. These figures are shown in the Table and indicate a consistent positive interaction. The data, being essentially percentages, might be converted to degrees for analysis. The interaction-term in degrees (see Table 10) also indicates a positive interaction. Thus the conventional interaction-term is of little interest in either the original or the transformed scale, and whilst the interaction should of course be separated from the experimental error in an analysis of variance, it cannot be regarded in this case as throwing any light on the question of the independence of the two factors.

It will often be found, when dealing with percentages and small whole numbers, that main effects are most naturally interpreted as additive on a log. scale. Transformation to degrees or square roots brings the data somewhat nearer to this scale, but not sufficiently near that the conventional test of an interaction in the transformed scale may be regarded as roughly equivalent to the real test of departure from independence. In such cases the true interaction must be tested separately by examining its consistency in the different replications. Where the transformation is itself a logarithmic one, it often equalizes the variances and provides the sensible test of interaction at the same time.

In conclusion, I have omitted for simplicity the discussion of the efficiency of estimation of main effects in the transformed scale. For this, reference should be made to Bartlett's 'Square-Root Transformations in the Analysis of Variance' [1], to which the present paper owes a great deal. It is, however, worth noting, that in the examples presented above of the square-root and inverse-sine transformations, the ratio of the treatments mean square to the error mean square is considerably increased by the transformation; the same is true if the example of § 2 is analysed in square roots, as Bartlett suggests. In my experience this is a common effect of a suitable transformation.

Summary

The analysis of variance is now widely applied in interpreting the results of replicated experiments. Sometimes, however, a combined analysis on the original data has little meaning and gives misleading results, because the treatments have different variances. A numerical example is given to illustrate such a case.

These cases may be divided into two groups. (1) With yield-data, or whole-number counts of over 100 per plot, they occur very rarely, but may do so if some treatment differences are of the order of several hundred per cent., or if there is a partial failure of certain treatments or plots. The analysis is best carried out by omitting some treatments or plots. (2) With small whole numbers or percentages, the distributions tend to follow the Poisson and binomial types, respectively, and there is a known relation between the variance and the mean. Data of this type should be transformed before an analysis to a scale on which the variances are equal.

Three transformations have proved particularly useful in practice. (*a*) The square root, for whole numbers per plot between 10 and 100. If the majority of the plot-yields are under 10, one-half should be added

to each plot-yield before taking the square root. (*b*) The inverse sine, i.e., the angle whose sine is the square root of the fraction, for percentages and fractions based on the ratio of small numbers. Percentages can, however, often be dealt with either by square roots, for small percentages, or by a direct analysis, for percentages from 30 to 70. (*c*) The logarithm, for distributions in which the standard error is proportional to the mean.

Numerical examples are worked, illustrating the use of each of these transformations and the way in which to present the results of the experiment.

A brief discussion is given of the analysis when the results consist of the number of plants in each of a number of grades (e.g. healthy, slightly diseased, severely diseased).

With factorial experiments in which the main effects produce large differences, the experimenter must consider what is the most natural definition of the independence of two factors, since the conventional test of interactions in either the original or the transformed scale may have little relation to this. A numerical example is given illustrating this point.

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THE RELATIVE VALUES OF ORGANIC AND INORGANIC FERTILIZERS FOR HOPS IN HEREFORDSHIRE

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IN Herefordshire, in addition to farm-yard manure, organic fertilizers are commonly used on hops. The experiment described below was undertaken to determine whether inorganic fertilizers give as high yields and a product of the same quality as do organic fertilizers.

The experiment was carried out on a loam soil planted to hops (Fuggle) in 1929. The stocks are spaced 39 in. apart in the rows, with 7 ft. between the rows. A Hereford hop acre consists of 1,000 stocks, but to avoid confusion all the figures given below refer to a statute acre of 1,915 stocks. Five bines are taken per stock, three on one string and two on another.

The whole experimental area received the following manurial treatment:

1933. 15 tons farm-yard manure and 8 cwt. potassic mineral phosphate per acre.
1934. 8 cwt. of a complete fertilizer (5·75 per cent. N, 7·75 per cent. w.s.P_2O_5, and 4·0 per cent. K_2O).
1935. 6 cwt. basic slag and 3 cwt. sulphate of potash per acre.
1937. 20 tons of farm-yard manure per acre.

The experimental treatments are given in Table 1.

TABLE 1. *Fertilizer Treatments*

	Fertilizer lb. per statute acre	*Nutrients lb. per statute acre*		
		N	P_2O_5	K_2O
A. Control	..	..	..	..
B. Organic: Peruvian guano	1,676	220	192	46
Superphosphate	82	..	11	..
Sulphate of potash	213	..	..	102
Muriate of potash	197	..	..	99
C. Inorganic: Concentrated Complete Fertilizer No. 1	1,716	213	216	256
D. Half Inorganic: Concentrated Complete Fertilizer No. 1	857	106	108	128
Half Organic: Peruvian guano	839	110	96	23
Superphosphate	42	..	6	..
Sulphate of potash	105	..	..	50
Muriate of potash	100	..	..	50

The experiment was continued on the same site for three years. The fertilizers were applied on April 23, 1935, April 16, 1936, and April 30, 1937.

The usual precautions were taken to control hop mildew, blight, &c. All plots were treated alike in this regard.

Lay-out.—The experiment took the form of a 4×4 Latin square. Each plot consisted of 40 stocks in two rows of 20. The plots were separated by two guard-rows each way.

The fertilizers were applied to the experimental rows and to the one adjacent guard-row.

Harvesting and drying.—In each season, all the plots were picked on one day. The dates of picking were: September 9, 1935, September 16, 1936, and September 10, 1937. The produce from each plot was kiln-dried separately. After cooling, the produce of the four plots in each treatment was bulked, and a representative sample taken from treatments B (organic) and C (inorganic) for quality tests.

Yields.—The yields of dried hops are shown in Table 2.

TABLE 2. *Yields of Dried Hops: cwt. per statute acre*

	1935	*1936*	*1937*	*Average per annum*
A. Control	13·71	12·00	10·47	12·06
B. Organics	16·96	17·18	13·54	15·89
C. Inorganics	18·90	19·18	16·00	18·03
D. Half organics and half inorganics	18·37	18·91	15·33	17·54
Standard error	0·698	0·364	1·091	0·484

All plots contained the same number of yielding bines, except plots C1 and C2, each of which contained one male plant, and plot D3, on which two stocks died during the 1936 season.

Correcting the yields for these differences has relatively little effect and, in any case, merely serves to accentuate the differences referred to below.

In all three years there was a highly significant response to fertilizers. On average over the three years, the inorganic fertilizers (C) gave significantly higher yields than the organic fertilizers (B); in individual years, the difference was highly significant in 1936 and approached significance in 1935 and 1937. The results with treatment D (half organic and half inorganic) are intermediate between those for the wholly organic (B) and wholly inorganic (C) treatments.

Hence, as far as yields are concerned it can be concluded that inorganics gave better results than organics.

Quality.—The preservative quality of the hops was assessed by estimating the total soft resins. The soft resins are divided into two fractions, the α resins or humulin, and the β resins or lupulin. The α fraction is three times more potent than the β fraction, and the preservative value (P.V.) is calculated from the following formula:

$$\text{P.V.} = 10\left(\alpha+\frac{\beta}{3}\right).$$

The moisture-content was also determined in order that the values for soft resins in the different years could be directly compared on a moisture-free basis. It is generally considered that the moisture-content should not exceed 10 per cent., or the hops will not keep well

on storage. In the present experiment, differences in moisture-content are likely to be partly due to variations in the drying process, so that it is not safe to draw any conclusions regarding the effect of treatment on moisture-content.

TABLE 3. *Preservative Quality of Hops*

	1935		*1936*		*1937*	
	B *Organic*	*C* *Inorganic*	*B* *Organic*	*C* *Inorganic*	*B* *Organic*	*C* *Inorganic*
Total soft resins, % .	13·00	12·60	13·67	13·81	13·82	14·21
α resins, % . .	6·64	6·40	5·81	6·85	5·23	5·68
β resins, % . .	6·36	6·20	7·90	6·96	8·59	8·53
Preservative value (P.V.) . . .	88	85	84	92	81	85
Moisture, % . .	10·0	10·43	9·9	9·5	11·50	9·14

The total soft resins and α and β fractions are expressed as percentages of the moisture-free material, in order that the different years may be compared directly. There is not much difference in P.V. figures between the treatments, and it can be concluded that the quality with inorganic fertilizers was at least as good as that with organic fertilizers.

Summary and Conclusions

In Herefordshire it is common to apply organic fertilizers as well as fairly frequent and generous applications of farm-yard manure to hops. The results of a three-year experiment show that the use of fertilizers in addition to farm-yard manure is justified, but that inorganic fertilizers gave significantly greater yields of dried hops than did organic fertilizers. The preservative value of the hops from plots treated with inorganic fertilizers was at least as good as that of hops from plots treated with organic fertilizers.

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ELECTRIC SOIL-HEATING

F. E. ROWLAND

WITH PLATE 8

Historical.—The production of plants out of season was practised by early civilizations, and the modern art may be said to have been founded in monasteries of the Middle Ages. As the monastic system developed earlier on the Continent than in England, progress in horticulture was more rapid there, and it is recorded that in Tudor times many vegetables were being imported into England from the Low Countries. An indication of the progress which was being made in market-gardens in London is recorded by Stowe in his *Survey of London*, who stated that in 1540 a slum was cleared in Smithfield for a market-garden to provide herbs and roots.

The first record of attempts of gardeners to protect their tender seedlings from frost appeared at the end of the sixteenth century, thick mattresses of straw being laid on long rods supported by forked sticks at each corner of the beds. This method was still employed towards the end of the seventeenth century, when it was used in conjunction with hot-beds, and it was also about this time or a little later that bell-glasses or cloches were introduced.

By the middle of the eighteenth century, market-gardens were established at Chelsea and Fulham, where certain specialized crops were grown under frames and cloches, covering large areas; and from this time until the end of the eighteenth century cauliflowers were exported regularly to many parts of the Continent.

During the eighteenth century, whilst cloches were principally employed in France, in England frames were more widely used and were being extensively developed. In 1781 John Abercrombie described frames very similar to those now in use, including single, double, and triple light types, as well as forcing pits and shallow frames for overwintering lettuce and cauliflower seedlings.

In the nineteenth century market-gardening was greatly influenced by advances in transport, the development of railways and steamships enabling the produce of temperate parts of France to be placed on the English market a few weeks in advance of home-grown varieties, and it is largely due to the intensification of this form of competition that growers to-day are anxious to use any method that will enable them to compete with the products of other countries.

Towards the end of the last and the beginning of this century, the use of frames by commercial growers in England was neglected, compared with that of glass-houses, as many of them considered that frames were more suited to private gardeners. This was partly due to the high cost of frames, which were well made and finished. In Holland a much lighter and cheaper type of frame was developed and used widely by commercial growers in open-field cultivation and by specialists for raising specific crops at all seasons.

Bottom heat in frames.—The principal means of producing bottom heat in garden frames are fermenting manure, hot-water or steam pipes, or electricity. In the early spring the air in frames is warmed by the sun, but to obtain rapid growth of plants it is necessary to raise the soil temperature as well, and the method most commonly used is to provide a layer of horse manure, which on fermentation generates heat rapidly. With the widespread use of mechanical transport, it is becoming increasingly difficult to obtain adequate supplies of manure; in fact, soon the principal sources will be racing and riding stables, which are, of course, comparatively few in number. Also, manure beds necessitate considerable skill and heating falls off as fermentation progresses. For these reasons other means for bottom heating are being sought. Experiments have been made with synthetic fertilizers and by innoculating straw with suitable bacteria, but so far these means have made but little headway.

Hot-water and steam pipes are also being employed, the former chiefly in commercial greenhouses, and the latter in outdoor frames. Iron pipes 2 in. in diameter are generally used for circulating hot water beneath the soil from special boilers, the soil temperature being maintained at about 10° F. above the surrounding soil, or at other temperatures that may be needed by particular plants.

Electric soil-heating.—Electricity offers obvious advantages for heating frames, particularly as regards convenience, cleanliness, and ease of control; its use being governed principally by working costs. Although, with present knowledge, its use on a large scale for commercial purposes is still considered to be too costly, there are undoubtedly many fields in which it is particularly advantageous. Ease of control, close temperature-operation, and immediate availability are particularly valuable, whilst its facility for dealing with a sudden drop in temperature or unexpected frost is unique. It may, therefore, be claimed that it is well worth further investigation and research to extend the sphere of electric soil-heating, especially when it is realized that its practical use dates back less than fifteen years, and that the cost of electricity is certain to fall as the use extends.

Electric soil-heating has been developed mainly for use in garden frames, where, owing to the small amount of air enclosed, heating is more economical. It has also been used to a less extent for supplementary heating in greenhouses, but as, up to the present, it has been chiefly applied to frames, this aspect of the subject will be considered in detail.

Construction of cable.—Specially insulated cables with resistance-conductors are generally employed for electric soil-heating. Experiments have been made with bare conductors operating at comparatively low voltages, but this method has not been used to any extent. The cables have to be of special construction, because those to transmit electricity are designed to work at as low a temperature as possible, and copper, which is the best commercial conductor, is employed. A soil-heating cable is akin to a heating element and consequently for the conductor a resistance-alloy is chosen, which runs at a high temperature and necessitates the use of insulating materials that will withstand heat, such as

asbestos yarn and oil-impregnated paper. The insulated conductor is lead-covered to exclude moisture, as well as to provide mechanical protection, and the lead covering is protected against corrosion in the soil by means of braiding impregnated with bituminous compound (Fig. 1). In the larger cables the conductor is straight, in smaller sizes it is spiralized round a central asbestos core to accommodate its comparatively greater length.

With the original cables, some difficulty was experienced in making a joint between them and the electricity-supply, and an innovation is the provision of tails about 18 in. long consisting of copper wire insulated with vulcanized india-rubber. This construction has two advantages; it not only effectively seals the heating cable against the escape of oil or

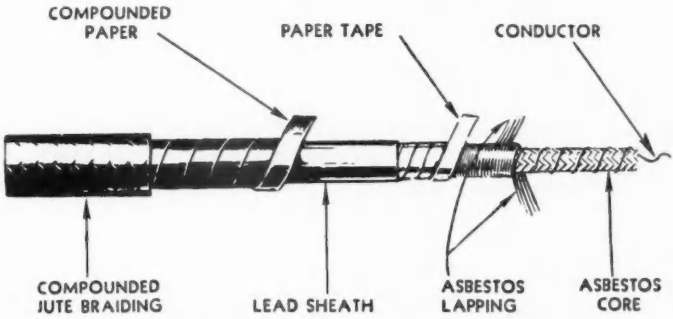

FIG. 1. Construction of typical electric soil-heating cable.

the ingress of moisture, but also facilitates its connexion and excludes excessive heat from the terminal box.

As the cables have to be rated to give a definite loading when specific voltages are applied, it is customary to supply them as units of definite lengths ready made up. A typical range of standard cables is given below:

Length ft.	*Loading* watts
25	125
100	490
150	700

For the home market this range is standardized for 230 volts, and whilst it can be used between 200 and 250 volts with a slight variation in wattage, it is not suitable in its standard form for widely different pressures, such as 100/110 volts.

Construction of beds.—In the early days of electric soil-heating, the cables were sometimes laid in earthenware drain-pipes, but nowadays it is usual to lay them in a bed of sand, the pipes having proved to be unnecessary and having the disadvantage that water is likely to lodge in them or drip on to the cable. The best way to construct a bed is to dig a pit of sufficient dimensions so that the bed can be lined at the bottom and round the sides with at least 1 ft. of ash, coke, or similar material to

provide heat-insulation. As the success or failure of electric soil-heating may be largely governed by economical operation, the conservation of heat in the bed and the prevention of its escape into the surrounding soil is important, and the effectiveness with which this is accomplished may make the difference between satisfactory and unsatisfactory operation. When the bed has been lined with heat-insulating material, a layer of sand about 2 in. deep is placed in the bottom and the cable laid in it. Soil is then added; the depth, which depends on the plants to be grown, is usually about 6 in. Current-consumption is proportional to the depth at which the cable is placed, the nearer it is to the surface, the lower is the consumption (Fig. 2). The cable is laid backwards and forwards in

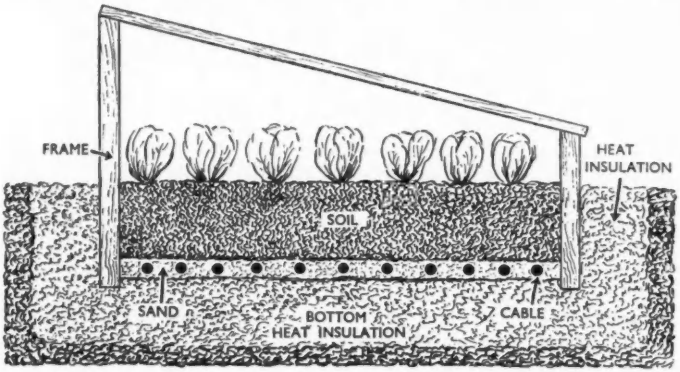

FIG. 2. Diagram showing method of constructing electric soil-heating bed.

zigzag fashion, the two ends being brought out in a convenient position for connexion to the electricity-supply.

Temperature-control.—One of the principal advantages of electric soil-heating is ease of temperature-control, and to obtain the maximum benefit a thermostat should be employed. By its use, selected temperatures can be maintained within close limits and entirely automatic operation secured. Soil-heating thermostats are generally of one or two types. In the one a robust rod is connected directly to the operating head, which is contained in a cast-iron case, connexion to the electricity-supply being by means of a flexible lead. The thermostat can be placed in any convenient position in the soil and is robust and unlikely to be damaged in ordinary use. In the other pattern the operating head is enclosed in a cast-iron case, mounted at the side of the bed, and to this a fine tube is connected, at the end of which there is a sensitive phial that can be taken to a convenient position in the bed from which the temperature is to be controlled.

Should it be preferred to dispense with a thermostat, manual operation or a time-switch may be employed. A time-switch is also necessary or desirable when 'off peak' or night heating only is used. However, the use of a thermostat is generally recommended, as its cost is soon saved

by economy in operation, and only by means of it can the full benefits of automatic temperature-control and even heating be secured. Plants usually grow more satisfactorily with a constant temperature, and a thermostat will also cope with the emergency of a sudden fall in temperature or unexpected frost.

The employment of 'off peak' or night heating only will frequently lead to cheaper operation. Many electricity-supply undertakings will offer considerable concessions if the load is disconnected during certain hours when the demand on their mains is at its maximum, generally between the hours of about 4 p.m. to 8 p.m. As soil is a good retainer of heat, there is no objection to the current being off for a short period.

Self-contained Electrically-heated Frames

Whilst electric bottom-heating is generally used directly in the ground, either in frames or greenhouses, it may also be applied in a self-contained frame, for use by both professional and amateur gardeners. Such a frame is equipped with a suitable heating-element and adjustable thermostat, and may be employed either in the open or in a greenhouse. The uses to which it may be put are many and include propagating seedlings or cuttings with gentle heat either direct in soil or sand, or else in boxes or pots; starting early plants and vegetables in soil; as a frost-proof frame for over-wintering tender species; early-season forcing of half-hardy annuals and perennials for subsequent bedding; for early salad and vegetable crops; and as a general-utility heated frame for starting plants, such as antirrhinums, begonias, and sweet peas. The ease with which the heat can be varied enables plants to be started at a high temperature and subsequently hardened off gradually without transplanting.

Application

It was intended to review the progress of electric soil-heating in various countries, and whilst it is known that considerable progress has been made in several north European countries, unfortunately the amount of information available suitable for publication is extremely small.

Northern Europe.—From Sweden it was reported as long ago as 1926 that 50,000 lettuce were grown in electrically-heated frames, whilst in Norway, in 1930, out of a total of 42,621 frames in use no less than 5,235 were electrically heated, which represents 12·3 per cent. of the total.

In Holland the possibilities of electric soil-heating have been investigated over a number of years. The Laboratory of Horticultural Plant Science at Wageningen reports that trials of electric soil-heating were started in the Netherlands in 1928, and that in the same year a bulb-grower at Heemstede erected frames covering about 2½ acres in a bulb field, whilst in 1929 there was another example covering nearly 4 acres. Since then, especially in the flower-growing district of Aalsmeer, and in the neighbourhood of Amsterdam, electric soil-heating has been adopted, and about thirty growers are now using it, especially for certain flower crops and for forcing chicory and young plants. Unfortunately, it is

impossible to give final details of the work in progress, as it is as yet unfinished (Plate 8, Fig. 3).

In northern Germany electric soil-heating has become part of normal commercial practice. With current at just under ¾*d.* per unit, the costs have been found to be favourable for electric heating compared with manure hot-beds, but in some instances the growth has been somewhat better with the latter, which may be due to the carbon dioxide produced in the bed, and it has been suggested that means might be devised for introducing it into electrically-heated frames.

England.—Some experiments carried out on Mr. F. A. Secrett's Holly Lodge Farm, Walton-on-Thames, by C. P. Quarrell, are reported in the *Journal of the Ministry of Agriculture* for August 1936. Although the results obtained were promising, the general conclusion is that the operating cost is too high; in view of certain factors in the experiment, this conclusion is likely to be misleading and in other circumstances the results might be very different. The benefit of a specially low tariff for 'off peak' operation was secured, and the current was switched off between 4 p.m. and 8 p.m. daily, but as the price paid per unit of electricity is not mentioned, it is difficult to draw comparisons. It is admitted that the construction of the beds did not include sufficient heat-insulation, whilst no additional protection was provided against frost, such as placing mats over the lights at night. The cable was laid at a depth of 9 in., which might have been less in this instance and would then no doubt have resulted in more economical operation.

However, it is interesting to note that, in spite of these handicaps, the average difference in soil temperatures between heated and 'control' frames was 5° F., which on very sunny days increased to 10° F., the maximum soil temperature in the heated frames being 67° and in the 'control' 57½°. The minimum temperature was 46° and 41° F. respectively, taken whilst the current was on. The temperatures aimed at do not appear to have been obtained consistently, which may be attributed to the low loading per square foot of bed.

Some of the results recorded include carrot seeds sown on Feb. 14, 1935, those in heated frames germinating about two days earlier than those in the 'controls'. The majority of the plants in the heated frames had reached the rough-leaf stage by March 7, although those in the 'controls' were only in the cotyledon stage. Lettuce planted on Feb. 14 were slightly further advanced on March 5, the date when heating ceased, and by March 14 the difference was very marked, although no heat had been applied for 9 days.

Although it was impossible to record accurate crop weights and market prices, the following observations were made: Mature lettuce were cut from heated frames on April 2, six days before any from the controls, and a greater percentage of first-grade lettuce was obtained from the former. The heated lettuce were also heavier, and this applied more particularly to the first two cuttings.

It is noteworthy that, in the heated frames, the lettuce near the junction box, where the cable came closer to the surface, matured earliest, which bears out the previous suggestion that the cable was

buried too deeply to obtain the best results, and a depth of 5 in. would probably have been more effective. The plants were of excellent quality and size. Although it is admitted that these experiments were not very successful, it is claimed that they provided information which should prove useful in further investigations and for obtaining more satisfactory results. The experiments were carried out in 7 rows each of 41 Dutch lights.

A grower in the north of England using a range of frames measuring 54×6 ft., equipped with soil-heating cable loaded at 5·6 kW., reported that he was perfectly satisfied with results from cuttings, some of which were ready in 9 months, compared with 2 years previously. Soil temperature was maintained thermostatically at 60° F., and an average weekly consumption of 264 units was recorded, which at ½*d.* per unit cost 11*s.*

Considerable interest has been displayed in the possibilities of using electric soil-heating for mushroom-growing, and a number of growers have adopted it successfully. At present some experiments are in progress to establish whether it is possible to reduce the amount of manure in the beds. Manure serves two purposes, fertilizing and heating, and as supplies are becoming scarce, it would be of great advantage if the quantity could be reduced. If, as is hoped, these experiments prove successful, this application may be extensively adopted.

United States.—It is reported from Cornell University that increasing shortage of manure makes it difficult to obtain supplies at the right time when propagating soft-wood cuttings in the summer, which is a common nursery practice. Consequently, an electric hot-bed, which is always ready for use, has great advantages over the older method. They have been used for several years for forcing vegetables, and it is suggested that there is no reason why they should not be employed generally, particularly for propagating cuttings in the summer. Results of three-year trials by two nurserymen show that electrically-heated hot-beds are practical and economical, whilst the longer period for which they can be employed makes their cost, construction, and use over a period of years considerably less than for manure beds.

Amongst other advantages of electric heating that these experiments have disclosed is permanence of construction, which enables an electric bed to be used for several years. Some well-constructed examples have been used for six years and longer, and it has not been found necessary to renew them at intervals when the crop is changed. An electric hot-bed is always ready for use, and even when it has been out of commission for a time, by turning on a switch it will warm up overnight, whilst a manure hot-bed, if it is required in a hurry, may take several days to construct and settle down to a suitable temperature. It is easy to provide good drainage with electric soil-heating, in fact, the methods recommended for the best construction employ ashes or similar material for the bottom of the bed, and this aids the striking of cuttings and avoids rotting. The ease of temperature-control and constant maintenance of a selected temperature have also been found to be outstanding benefits, whilst continuity of availability and use, as well as having the beds ready at any

time, enables them to be employed for many purposes, such as for propagating evergreen cuttings in the autumn, and forcing vegetables and perennials in the spring. When a number of hot-beds is employed, different temperatures may be used so as to grow various plants or cuttings, and it is easy to lower the temperature to harden off before planting out. The opinion is expressed that every nurseryman and market-gardener can well afford at least a small-scale experiment under his own conditions.

Amongst interesting experiments reported by the Department of Ornamental Horticulture, Cornell University, and the Missouri Agricultural Experiment Station, the following comparative costs are given for a 4-light frame:

Manure bed	$	*Electric bed*	$
2 loads manure	6·00	1 thermostat	8·50
3 cu. yds. sand	5·55	150 ft. lead heating cable	9·00
11 hours labour to prepare	3·30	3 cu. yds. sand	5·55
6 hours labour to remove sand afterwards	1·80	3 hours labour to prepare	0·90
	$16·65		$23·95

The cost of making the frame, digging, and cinders was the same in each case, and the electrical bed could be used for three years, whereas that with manure had to be remade every year. The cost of electricity for three years was $3·84, $7·92, and $4 respectively.

Mr. G. A. Reitz, of the American General Electric Company, reports that in the United States electric soil-heating has become a load of real interest to Supply Authorities and that about 5,000 kW. is connected. This accounts for an annual consumption of 4,000,000 kWh., which is an attractive load, as most of it is taken at night. The operating costs have proved lower than was expected, and so growers have adopted electric soil-heating extensively. It is also reported that, whilst automatic thermostatic control is not essential, it is recommended, because, in spite of the first cost being somewhat higher, the final expense is less owing to the prevention of wastage of energy. Some typical results are reported from Cleveland and are summarized below:

EXAMPLE 1. Propagating bench in greenhouse. Soil temperature 60° F.—air temperature 40–55° F. First batch of 20 dahlia cuttings all rooted compared with 70 per cent. formerly. Carnations rooted 100 per cent. compared with 30 per cent.

Financial result	$
Six additional plants, average $5	30·00
Electric heating, including heating for some tubers	4·00
Additional profit	26·00

EXAMPLE 2. Propagating bench in greenhouse and plant seed house. Coleus rooted in about a third of the time, and approximately 6,000 plants grown in same area and in same time as previously required for 2,000 plants.

Financial result	$
Additional 4,000 plants	40·00
Electric heating	3·60
Additional profit	36·40

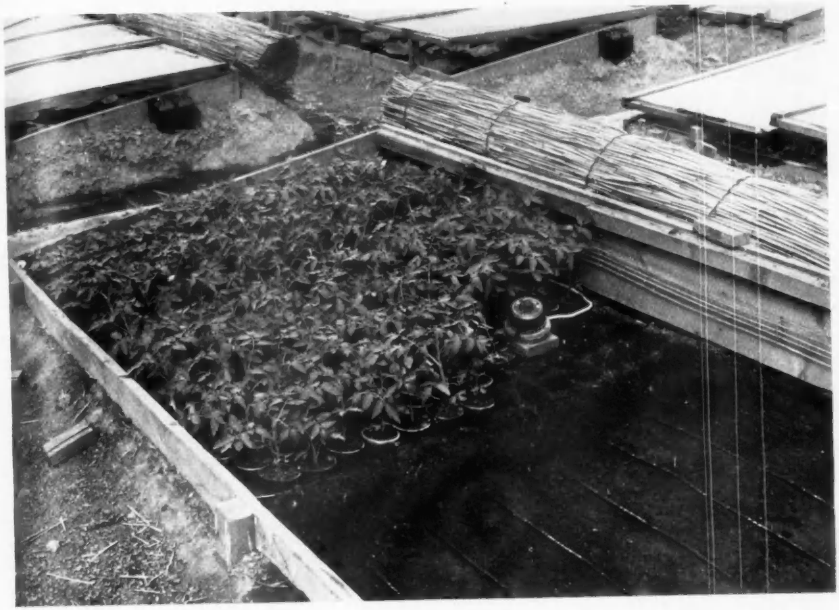

FIG. 3. Tomato plants in frame, thermostatically controlled and electrically heated (Holland)

FIG. 4. Comparison of early potatoes with and without electric soil-heating

EXAMPLE 3. Propagating bench in greenhouse. Soil temperature 60–65° F. Air temperature 60° F. Geranium slips rooted in 7 days—a third of normal time. Rapid rooting enabled extra cutting to be obtained from new plant, which was rooted for the same market.

Financial result	$
Second cuttings	30·00
Plants formerly lost by not rooting	7·50
Electric heating	2·00
Additional profit	35·50

EXAMPLE 4. Greenhouse propagating bench for dahlias. Thirty-five seedlings transplanted from contaminated soil when two weeks old. Seedlings continued to grow without loss. Former loss 20 to 30 per cent. in dahlia cuttings eliminated. Value per cutting $3 to $10. During a cold spell when the temperature in the greenhouse dropped to freezing, there were no losses in the electric bed.

Financial result	$
Seedlings	12·50
Electric heating	5·09
Additional profit	7·41

EXAMPLE 5. Frame in greenhouse used for tomato plants. Time of growth reduced by more than a third, and 6,000 plants per ounce of seed compared with 4,000 previously. The lights were left off during the night on several occasions, and the heated section was not insulated from the unheated.

Financial result	$
Saving of seed for 18,000 plants	4·00
Saving of coal—10 tons	25·00
Electric heating	13·16
Additional profit	15·84

EXAMPLE 6. Ten benches each 60 × 5 ft. in greenhouse for roses for cut-flower market. An increase of one bloom per plant per month was obtained, and in March 1933 the increase was 2,500 blooms compared with the previous March. The greenhouse air temperature was reduced from 80° to approximately 60° F., and the soil temperature was maintained at 65° to 70° F. By varying the air and soil temperature the grower was enabled to hasten or hold back the development of blooms.

Financial results	$
Additional blooms	146·00
Saving in coal—20 tons	50·00
Electric heating	37·86
Additional profit	158·14

Acknowledgement. Whilst some sources of information are referred to in the text, use has also been made of the following publications, to which reference can be made for further details:

Crop Production in Frames, Ministry of Agriculture and Fisheries, Bull. No. 65.
R. R. PARKS, Electric Hotbeds, Missouri Agric. Exp. Stat., Bull. No. 304.
D. WYMAN and M. W. NIXON, Electric Hotbeds for Propagating Woody Cuttings, Cornell Univ. Agric. Exp. Stat., Bull. No. 618.

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XUM

PRELIMINARY WORK ON THE ARTIFICIAL INSEMINATION OF LIVE STOCK IN PALESTINE

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THE two main systems of agriculture in present-day Palestine are remarkable for their extreme diversity. On the one hand is the Arab peasant, whose agricultural practices have remained essentially unchanged for twelve centuries; and on the other the Jewish colonist, whose methods are the quintessence of modernism. Strange as it may seem, these two diverse cultures have something in common, for both have contributed to the development of the animal-breeding technique known as artificial insemination. In very early times the Arabs are known to have applied it in the breeding of their horses, whilst the Jewish settlers of to-day are developing the same method along modern lines with a view to organizing its application as a routine practice in the breeding of dairy cattle, and perhaps in the breeding of all classes of stock. The former instance is of historical interest only, the latter work forms the subject of this paper.

During recent years, interest in the possibilities of artificial insemination in Palestine was first aroused as the result of a trial conducted by Dr. M. Sturman, veterinary practitioner, in 1932. Three cows, which were infected with contagious abortion, were inseminated with sperm collected by the 'sponge' method. Although one of the cows became pregnant, the work was discontinued at that time on account of inexperience and a lack of proper instruments. In August 1934 a further trial was undertaken by Dr. H. Fox, veterinary practitioner, who worked with cattle, sheep, and goats at the Government Stock Farm, Acre, and in the Jewish group-settlements in the Valley of Esdraelon. Twenty-five animals were inseminated, 14 of which became pregnant, and 19 healthy young were born. The comparatively low rate of pregnancy in this case (56 per cent.) was attributed to the lack of modern equipment, in the absence of which the unsatisfactory 'sponge' method of sperm collection was again used. Twelve cows which had been unsuccessfully treated for chronic sterility were inseminated in December of the same year, and 3 of these conceived and gave birth to normal calves at term. A further 6 healthy cows were inseminated in January 1935, and 3 of these became pregnant. So far artificial insemination had been purely an experiment and there appeared little likelihood of its being applied to practical stock-breeding in Palestine. At this point, however, a situation arose which gave advocates of the method a chance to prove its genuine value.

In the autumn of 1935 there was a serious outbreak of infectious vaginitis among the dairy cows in the Ain Harod area. The valuable stud bulls contracted balanitis and breeding had to be stopped. Moreover, it soon became apparent that treatment would take a long time, and meanwhile stock-owners were likely to suffer considerable losses

from the absence of pregnancy. An examination of the infected cows revealed the fact that in most cases the internal sex organs were normal. If insemination could be effected, therefore, pregnancy was likely to result, in spite of the inflamed condition of the vagina. This hypothesis was tested by introducing a healthy bull of the native breed. The bull was allowed to cover 10 of the infected cows, and 8 of these became pregnant after the first service. As was to be expected, the bull contracted balanitis and became unfit for further breeding. In any case it was realized that the progeny of local bulls were not likely to grow into dairy stock of the desirable type, and the problem was to find a method by which pure-bred bulls could be used without exposing them to infection. A solution was found in the technique of artificial insemination.

Dr. Fox started to work in December 1935, and by the following February 52 cows had been inseminated. An artificial vagina of the 'Cambridge' pattern was used for sperm collection, and semen collected in this way was found to be purer and more concentrated than that obtained by the 'sponge' method. Of the healthy cows inseminated, 83 per cent. became pregnant; among the infected cows the corresponding percentage was 50, whilst 7 heifers, each of which was given a single insemination, all conceived. Artificial insemination had proved to be effective in combating sterility and also in checking the spread of infectious vaginitis, for no fresh cases of the disease occurred.

By this time the settlers were beginning to interest themselves in the economic advantages of the method, for among these settlers, more strikingly, perhaps, than among the farmers of any other country, to hint at a possibility of reducing costs, and thereby of increasing profits, is all the stimulus which is necessary to launch an immediate inquiry. It was obvious that if artificial insemination were adopted as a routine breeding-method, the number of herd sires could be considerably reduced, and corresponding savings could be effected in the expenditure previously incurred on their maintenance. These savings were not, however, likely to be sufficient to warrant the employment of a full-time veterinary surgeon to conduct the insemination work, and it was therefore arranged that cows in heat should be collected in the evening from the surrounding settlements and brought for insemination to the local veterinary practitioner.

In order to test the practicability of artificial insemination on a comparatively large scale, an experiment was planned to last for one year, during which half of the cows in a given area were to be served in the usual way, and the other half were to be artificially inseminated. This work was begun in August 1936, under the supervision of Dr. Sturman. By the end of July 1937, 226 cows had each been given a single insemination, and 51·3 per cent. had become pregnant. During the same period 172 cows were served in the natural way and 49·4 per cent. of these conceived. The detailed results are given in the table on the next page.

It will be observed that during the first few months of the experiment a higher percentage of settling was obtained by natural service than from artificial insemination, but as the operators improved in skill, it was found that artificial insemination gave the higher percentage of

pregnancies. Even so, the results obtained by this method compare unfavourably with those realized in similar experiments in other countries. This was due, in a large measure, to the use of unreliable clinical material. Of the 111 cows which were inseminated but did not conceive, 60 were found to be suffering from diseases of the internal sexual organs, and a further 9 were completely sterile. If these 69 cows are eliminated from the calculation, the rate of pregnancy following artificial insemination rises to 68·6 per cent., a far more satisfactory figure. Furthermore, it must be remembered that the work was carried out under the most primitive conditions, by inexperienced men, and with only the bare essentials of equipment. An example will serve to illus-

Comparison of Percentage Fertility Resulting from Natural Service and from Artificial Insemination

	Natural service			*Artificial insemination*		
Month	*No. of cows served*	*No. of resulting pregnancies*	*Settling percentage*	*No. of cows inseminated*	*No. of resulting pregnancies*	*Settling percentage*
1936 August	24	12	50·0	26	8	30·8
September	19	8	42·2	18	5	27·7
October	25	11	44·0	21	7	33·3
November	26	10	38·5	30	14	46·5
December	29	15	51·7	36	20	53·3
1937 January	23	15	65·2	34	23	67·6
February	26	14	53·8	27	15	55·5
March	..	..	..	7	6	85·7
April	..	..	..	10	7	70·0
May	..	..	..	2	1	50·0
June	..	..	..	4	3	75·0
July	..	..	..	11	7	63·6
Total	172	85	49·4	226	116	51·3

trate the effect of external conditions upon the results obtained. In the 226 inseminations performed in this experiment, the operations of sperm collection and insemination were carried out in one building; and the resulting settling percentage was 51·3. The corresponding percentage for 69 cows inseminated in outlying settlements, in which the two operations could not be performed in one building, was 42·6. This difference can only be attributed to the adverse effect of momentary exposure of the semen to the sun's rays or to a sudden change of temperature. With regard to the effects of the inexperience of the operators, it will be observed that the average settling percentage obtained was 25 per cent. higher in the second than in the first three months of the work, whereas the settling percentage for natural service remained more or less the same throughout. Similarly with regard to equipment, it was found that sperm collected in the artificial vagina gave an average increase in fertility of 20 per cent. over that collected by the antiquated 'sponge' method.

In all the work performed so far, undiluted semen has been used.

The normal practice has been to make a single injection of 1 c.c. of the fresh material as soon as possible after collection. The results obtained, although not entirely satisfactory, were nevertheless sufficiently encouraging to warrant a recent extension of operations to include three additional colonies. No sound experimental work on the technique of dilution, or on the possibilities of the conservation and transport of semen, have yet been undertaken in Palestine. It is clearly desirable that this experimental work should precede, and its results form the basis of, any attempt to introduce artificial insemination on a practical scale. With this end in view, the necessary equipment has been assembled, and it is expected that experimental work on the dilution, storage, and transport of sperm will soon be undertaken.

In Palestine the method of artificial insemination offers many advantages; these may be considered from a veterinary, a breeding, and, most important, from an economic point of view. From the veterinary standpoint the method offers the possibility of inseminating cows suffering from diseases of the external sexual organs, such as infectious vaginitis, and from anatomical defects of these organs, such as stricture of the uterine os. In general infections, for example in contagious abortion, the losses which result from the impracticability of natural service in such circumstances may be avoided, since artificial insemination is possible without endangering the health of the sire. On account of this fact, too, the method is likely to prove of value in Palestine in controlling the spread of dourine (an equine trypanosomiasis).

The advantages to the breeder are well recognized. The likelihood of conception is increased, and a considerable economy of spermatozoa is effected, because the semen is deposited directly into the cervix of the uterus. Further, since potent sperm may be transported to a distance, the field of usefulness of a valuable sire is greatly extended, and the breeder may avail himself of a greater choice of males. The development of the technique of dilution and micro-insemination permits of an enormous increase in the number of young which may be sired in the lifetime of a single outstanding male.

As an example of a field in which these advantages are likely to find practical application, mention may be made of the development of the breeding of Karakul sheep in Palestine. The native Palestinian sheep is closely related to the Karakul, and pure-bred Karakul rams were imported from Germany and Rumania in 1934 for crossing on the local ewes with a view to the production of Karakul lamb-skins. The pelts of both first-cross and second-cross lambs have proved to be highly satisfactory and are likely to realize good prices on the London market. In Palestine, however, sheep are kept primarily for milk production, and the success or failure of the experiment depends upon the milk-yield of the cross-bred ewes, a matter which is now under investigation at the Government Stock Farm. There are indications that the milk-yield will be satisfactory, and should this prove to be the case, the only remaining difficulty is that of procuring a sufficient number of pure-bred Karakul sires for breeding. Even if a sufficient number were available, the cost of imported pure-bred rams is prohibitive, and a practical solution to

this problem lies in rapidly increasing the number of pure-bred Karakul stock already in the country by the method of artificial insemination.

From the economic point of view, the main advantage of artificial insemination lies in the possibility of reducing the number of sires and of reducing thereby the cost of production of progeny. The figures given in the foregoing table will serve to illustrate this point. Three mature bulls had to be kept in order to perform 172 natural services in a period of 7 months. One hundred and ninety-two artificial inseminations required only 81 ejaculations from one bull, and even so the quantity of semen obtained was far in excess of actual requirements. It is safe to assume that with better organization at least 250 cows could be inseminated with the undiluted semen obtained from a single bull in the course of a year. Since in natural service it is necessary to keep one bull to serve every 50 cows, it will be realized that artificial insemination offers the immediate possibility of reducing the necessary number of bulls by 75 per cent. The services of the average pure-bred bull used in calf-production cost approximately £50 per annum. This sum is made up of depreciation, interest on capital outlay, cost of feeding, labour, and other charges. Each bull sires about 50 calves in the course of a year, and the cost of the breeding service is, therefore, roughly £1 per calf. When the method of artificial insemination is employed each bull becomes the potential sire of 250 calves per year, and the cost of breeding per calf is reduced to 4*s*. (plus a small charge for the service of a skilled operator). If sperm-dilution is practised, the number of calves sired by a single bull in the course of a year may be increased one hundred fold. Such considerations lead one to envisage a Palestine Stock-Breeding Service which would have as its basis a country-wide network of artificial-insemination stations. Technical obstacles there are none; the difficulties are those of organization.

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ARTIFICIAL INSEMINATION OF CATTLE AND SHEEP IN KENYA

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Introductory Note by R. DAUBNEY

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WITH PLATE 9

IT may be useful to explain briefly why the Kenya Veterinary Department is interested in the practical application of the artificial-insemination technique, as developed largely by the Russians in the post-War period. In the first place, we have for some years been aware that the reproduction-rate for cattle, more particularly for 'grade' cattle on the European-owned farms, is far from satisfactory. It was for this reason that the work at the Experimental Station at Naivasha, which formerly had been confined to nutritional investigations under the direction of Sir John Orr, of the Rowett Research Institute, was re-oriented in the direction of discovering or attempting to discover whether nutritional deficiencies were responsible for the low reproduction-rate in Kenya. This particular line of research demanded some preliminary comparative investigations of fertility-rates in Kenya cattle, and service into the artificial vagina proved to be the only satisfactory method of testing the fertility of a bull. At this stage it became apparent that the incidence of sterility in bulls was unusually high.

As far back as 1928 we had noticed the occurrence of waves of temporary sterility, with regularly recurrent oestrus, which would affect entire herds, persisting sometimes for a year or more, and eventually leaving behind from 5 to 20 per cent. of permanently sterile cows. Clinically, the only abnormalities shown by the cows during the sterile period were those commonly ascribed to contagious granular vaginitis, but in the permanently sterile cows dysfunction was almost always due to a chronic fibrous peritonitis affecting the pavilion and fallopian tubes and rendering proper ovulation impossible; ovulation not infrequently occurred into the peritoneal cavity. It was a common occurrence during such outbreaks for lesions to appear on the penis or on the sheath of the bull, and on several occasions bulls were seen to become permanently sterile after an outbreak had occurred in the herd. In the permanently sterile bulls the usual lesion was a fibrous induration and enlargement of the epididymis with pressure atrophy of the testicle itself, but occasionally purulent foci were found in the testicle or in the epididymis. There was some indication that at times the disease in cattle had been spread by such affected bulls, and that an outbreak in cows had followed the introduction of an infected bull from a farm in which a previous outbreak had occurred. Attempts on several occasions to transmit the disease to cows and bulls failed.

When Dr. Anderson began a systematic examination of bulls for fertility it was early apparent that there was a large percentage of sterile

bulls in the country, and that the great majority of the sterile animals showed clinical abnormalities consisting of fibrous epididymitis with considerable enlargement. Of 130 bulls that gave poor, dead, or absent sperm, or refused to serve for test, 90 showed clinically recognizable changes affecting testicle and epididymis (unpublished results). It may be significant that on European farms the disease has only been in pure-bred or grade animals of European breeds, although the Masai are apparently quite familiar with the condition, using for it the same word that they use for gonorrhoea in man.

Here, then, was the first reason for our interest in artificial insemination. In the absence of definite proof it has been assumed that the disease in question is spread by coitus, and obviously the most serious risk is that to the bull, which may be an expensive pure-bred imported animal. With the insemination method now followed the bull is never allowed to serve a cow, and accordingly runs no risk of infection. Equally the insemination of cows with sterilized instruments as opposed to natural service greatly reduces the chance of mechanical spread from one infected cow to another.

Another aspect of the matter, and one which is particularly pertinent in young countries where native foundation stock is being graded up, is the tendency for farms, especially dairy farms, to be 'underbulled'. A pure-bred bull, whether country-bred or imported, is expensive, and in a desire to make the best possible use of him he is frequently overworked, with disastrous effect on the length of his useful life. Artificial insemination not only economizes greatly in the use of sperm, so that many more cows can be fertilized from each service, but since the ejaculation is submitted at each service to some kind of examination, preferably microscopical, one can exercise a closer control on the health and fertility of the sire. If the bull needs resting the fact is at once evident from the examination of sperm, and he is rested; whereas in the ordinary event the fact may not be noticed until large numbers of cows have returned and have been re-served, often with disastrous results to the virility of the sire.

In the last section of his paper Dr. Anderson refers to the immense advantage offered by artificial insemination as a means of grading up both cattle and sheep in the native reserves. It is, in fact, the only method of accelerating the progress of grading up native sheep for wool production, unless one has very large sums of money at one's disposal to buy rams.

In those reserves where East Coast fever is enzootic one is enabled to use at inseminating centres improved native bulls of good milking strain, which would die of East Coast fever if exposed in the ordinary way for service in the villages. In the pastoral reserves that are naturally suited to the ranching of beef cattle, it is probable that the half-bred produced by a top-cross with a good British beef sire on a native cow will produce an animal of a quality suitable for the chilled meat trade.

In all these directions artificial insemination should assist in the economic development of a country such as Kenya; and an intimate knowledge of the experimental work that has been carried out at the

Naivasha Station is sufficient to convince one that the method is a practical one and, as Dr. Anderson states, the main problem is now one of field organization.

Introduction.—Artificial insemination is now used extensively and very successfully in breeding horses, cattle, and sheep in Russia; and in general the results are very similar to those obtained from natural mating. In the U.S.S.R., in 1936, there were 8,000 insemination centres for sheep and 1,350 centres for cattle with an average of 800 and 170 animals respectively. In that year 230,000 cows were inseminated [1], compared with 165,000 in 1933 [2]. In 1935 the average percentage of conceptions for cows was 93·7, and in one district, where 160 bulls were formerly required, 37 bulls impregnated 8,000 cows. The maximum number of cows inseminated with sperm from one bull was 1,090 [1].

Results with sheep have been even better. The number of ewes inseminated annually has increased from 920,000 in 1932 to 6,450,000 in 1936, which is three times as much as in 1935. In 1932 the percentage of conceptions was 82·4, which compares very favourably with the percentage of conceptions (79·6) in 1,560,000 ewes served normally [3]. Also, in 1933 the percentage of conceptions in 1,500,000 ewes inseminated was equal to or above that of normal service [2]; in 31,911 Karakul ewes the percentage was 79·4 [4]. In 1935 the average percentage of conceptions was 96·6; in some districts 100 per cent. was obtained. The maximum number of ewes inseminated with sperm from 1 ram was 15,000, and in one district the entire population of 45,000 ewes was inseminated with the sperm from 8 rams, whereas it is stated that 900 rams would have been required for natural mating [1].

Material and Methods

The technique used in Kenya is that of the Russian workers. A description of the method is available in the monograph of the Imperial Bureau of Animal Genetics [5], and more recent accounts have been given by Walton [6] and Anderson [7, 8]. The method is essentially the same for cattle and sheep. The general procedure consists in (1) collecting the sperm from a sire by means of the artificial vagina, (2) microscopical examination and dilution of the sperm, and (3) injecting the sperm into the cervix of the female.

The fertility of sires is thoroughly tested before artificial insemination by collecting several specimens of sperm with the artificial vagina and noting the following points: ability and keenness to mate, volume, motility, and density of the sperm, and the percentage of abnormal types of sperm present. Only producers of first-class sperm should be used for artificial insemination. Also, any available, reliable breeding records, based on services with normal healthy cows with good breeding-records, should be used when arriving at an estimate of the bull's fertility. With a ram, it is usual to allow him to serve a small group of ewes a month or so before the beginning of the breeding-season and see how he 'settles' them. Besides these preliminary tests, every specimen of sperm collected

for insemination should be examined for density and motility, and only specimens showing numerous highly motile sperm should be used.

The cow or ewe which is to be inseminated must be 'on heat'. 'Teaser' males are used to pick out animals on heat. Vasectomized and vasoligated bulls and rams or aproned rams were used for this purpose in the experiments described in this paper. On two of the farms the teaser bulls were put with the cows when they came in for milking either morning or morning and evening, and on the other farm they were run with the cows all the time. Teaser rams were put with the flock once daily. One insemination was carried out during a single heat-period with both cows and ewes.

The following remarks apply to the cleaning of apparatus for both cattle and sheep. When new, and after use, the artificial vagina should be cleaned with hot water and washing soda with a bottle brush. It is then thoroughly rinsed with water and wiped out with 65 per cent. alcohol, the swab-holder being used for this purpose. The artificial vagina should be kept in a place free from dust. Glassware is treated similarly. Bottles and test-tubes can be plugged with cotton wool to keep out dust. Pipettes should be rinsed out immediately after use, as the sperm is difficult to remove once it has dried. The syringe and vulcanite nozzle, when new and also immediately after use, should be rinsed out with cold water, and the former should be filled with 65 per cent. alcohol and left filled until ready for use. The alcohol is then washed out with clean, boiled water, and the syringe and nozzle are finally rinsed out two or three times with 'dilutor'.[1]

Artificial insemination of cattle.—For the collection of sperm a cow on heat is required, and preferably an older cow that has been handled a lot and stands quietly. The cow should be tied to a post with a halter or with rope round the horns. The ground should be level and not slippery. There should be no difficulty in getting a bull to mount the cow, particularly once he has become accustomed to the procedure. The bull should be led up to the cow on a halter or with a pole attached to the ring; and there should be enough space behind the cow to allow the bull to be moved round if he does not mount the cow at once. As Walton points out, it is of great advantage if the same yard is used for all services and collections, so that the bull becomes thoroughly accustomed to the surroundings, and when led to the yard expects service.

If possible a separate building should be kept solely for artificial insemination. No disinfectants or strong-smelling chemicals should be allowed in this building, as they are harmful to the sperm. The apparatus should be laid out on a table covered with a clean cloth or sheets of blotting paper. The artificial vagina is swabbed with 65 per cent. alcohol and when dry smeared with medicinal liquid paraffin. Water, which has been heated to 45° C., is filled into the cap end of the vagina, and the free end of the rubber lining is then folded back and tied in place with string.

In preparing the artificial vagina (Plate 9, Fig. 1) the small glass

[1] 'Dilutor' is the word coined to denote the composite fluid used for diluting the sperm.—*Edit.*

bottle, containing about 2 m.l. of medicinal paraffin, is inserted into the small end of the artificial vagina and is held in place by the metal cup, which is screwed on. The correct distension of the artificial vagina is then obtained either by blowing air into it or by running water out through the tap.

A small quantity of liquid paraffin is then poured into the artificial vagina to lubricate it thoroughly. The temperature should be between 39° C. and 43° C. If it is too cold more hot water must be added, and if it is too hot it must be allowed to cool to the proper temperature before use. There is always a slight delay between filling the artificial vagina and collecting the sperm, for which allowance must be made. The temperature, which should be read immediately before collecting the sperm, should lie between 38° C. and 42° C. The artificial vagina is now ready for use.

To collect semen the collector stands on the off-side of the cow, holding the artificial vagina by the handle in the right hand. When the bull mounts the cow the artificial vagina is raised close to the flank of the cow at an angle corresponding to the probable line of erection of the penis. The penis is directed into the artificial vagina with the left hand, which grasps the sheath; it should not be touched by hand, as this may cause retraction. When the penis enters the artificial vagina the bull thrusts vigorously forward and upward and ejaculates into the artificial vagina. Sometimes this may not happen immediately the penis enters the artificial vagina, and occasionally a bull will mount the cow two or three times before ejaculation occurs. A bull does not ejaculate unless he has this final upward thrust. When the bull has ejaculated he dismounts from the cow. The artificial vagina should be tilted with the cup-end lower than the open end so that the sperm does not run out; it should be held in position at the end of the sheath for a moment after ejaculation to catch any final drops of sperm (Plate 9, Fig. 3).

To collect the sperm the bottle containing it is removed from the artificial vagina, care being taken to avoid exposure to the sun. A normal ejaculation, amounting to about 5 m.l., is a thick, milky-white fluid containing living spermatozoa. Usually the whiter and thicker the specimen the more numerous are the spermatozoa it contains. A less dense specimen is more transparent and bluish-white. Movement of the sperm can very often be detected by the naked eye. Every specimen of sperm, however, should be examined microscopically by the hanging-drop method, using a hollow-ground slide and cover-slip. A good specimen of sperm should show very active movement; in a dense specimen this is seen in the form of characteristic turbulent wave-movements. The sperm is examined immediately after collection and preferably on a warm stage at body-temperature. If this examination is delayed the fall in temperature may reduce the degree of activity of the spermatozoa.

Whether dilution is required or not depends on the number of cows to be inseminated. Bull sperm can be diluted safely with the dilutor up to 3 times its volume.

The sperm is measured and transferred to a test-tube, the appropriate amount of dilutor is added, drop by drop, the two being mixed by

gently inverting the tube several times. The syringe and nozzle are rinsed out two or three times with the dilutor and the diluted sperm taken up.

Cows in Kenya have a shorter heat-period than cows in temperate climates, and heat is usually less intense [9]. Heat may therefore be easily missed unless the bull is run with the cows. The best method of detecting a cow on heat is to run a teaser bull with the herd, or to put this bull with the herd twice a day, morning and evening.

For the actual insemination the cow is secured in a milking bail and the legs tied if necessary (Plate 9, Fig. 4). The vulval region is cleaned with a sponge soaked in water. The sponge is then squeezed out and the vulva dried. A disinfectant must not be used for this purpose. The speculum is now introduced by an assistant, with the handle turned to one side. The speculum is then turned round and opened and moved about until the cervix is exposed. The tip of the nozzle is introduced about 1½ cm. into the cervix and 1 m.l. of sperm is injected slowly, so that all the sperm remains in the cervix. The syringe is then withdrawn, followed by the speculum. If another cow is to be inseminated the nozzle is cleaned with a cotton-wool swab soaked in 65 per cent. alcohol and dried with a dry swab. This is repeated before each cow is inseminated.

Artificial insemination of sheep.—For collecting the sperm a ewe on heat is required (or a quiet ewe that is held to prevent her moving about when the ram mounts her). The ram should be quiet and easily handled. Young rams are often wild and though sexually virile pay no attention to a ewe on heat, particularly in strange surroundings. If such rams are handled frequently and are exercised on a halter they will soon settle down. Young rams that have not served before should be allowed to serve two or three ewes before sperm is collected with the artificial vagina. As with the bull, it is an advantage to collect sperm always in the one place or building, in order that the ram may become accustomed to his surroundings. When the ewe and the collector are in position the ram should be led up to the ewe, and he should mount almost immediately.

The artificial vagina is prepared in the same way as that for the bull. The correct distension, which is learnt by experience, is obtained by means of the tap on the side of the artificial vagina. The pressure required varies from ram to ram. The correct temperature at the time of collection of sperm lies between 38° C. and 42° C.

To collect sperm the artificial vagina is held against the flank of the ewe, and when the ram mounts, the penis is directed into the artificial vagina with the left hand applied to the sheath. When the penis, which must not be touched by the hand, enters the artificial vagina the ram should thrust upwards and ejaculate sperm into the upper end of the artificial vagina, or into the bottle. The artificial vagina is then held vertically to allow the sperm to run into the bottle. Some rams are slower than others in ejaculating, and some may mount the ewe two or three times before they have a final thrust and ejaculation. A normal ejaculation from the Merino ram measures about 0·7 m.l., and is a thick, creamy-white fluid containing living spermatozoa. The motility should

be very strong and the characteristic turbulent wave-movements should be seen. The sperm is then diluted to the required degree. Up to seven volumes of dilutor GPS 2 can be added; it is added drop by drop to the sperm and the two are mixed by gently shaking the tube. The syringe is rinsed out two or three times with the dilutor and the diluted sperm is then taken up in the syringe. For insemination the ewe should be stood on a table or placed on a rail 3½-4 ft. high. The speculum and syringe are disinfected with a cotton-wool swab soaked in 65 per cent. alcohol and then dried with a dry swab. The speculum is then inserted into the vagina with the left hand, with the flat side of the blades vertical. It is then turned so that the handle points downwards and the cervix exposed. The tip of the syringe is inserted about 1 cm. into the cervix and 0·2 m.l. of sperm is injected. The syringe and speculum are then withdrawn and disinfected before inseminating another ewe.

Dilutors.—The dilutor used for cattle is a glucose-tartaric solution —GTC [10] containing potassium sodium tartrate 25·6 gm., glucose 12·0 gm., salt-free peptone 5·0 gm., distilled water 1 litre. Witte's peptone is usually used instead of salt-free peptone. Originally this dilutor was made up in two parts, one containing the glucose, and the other the potassium sodium tartrate and the peptone, the two being mixed when required. Latterly, however, the dilutor has been made up in the one solution.

The dilutor used for ram sperm is GPS 2, composed as follows [11]: Solution 1 (gm. per litre of water), anhydrous glucose 64·0, KH_2PO_4 1·7; Solution 2 (gm. per litre of water) $Na_2HPO_4 \cdot 12H_2O$ 41·6, $CaHPO_4$ 0·1, $MgHPO_4$ 0·1. In the present experiments the equivalent amount of anhydrous disodium hydrogen phosphate was used in place of the $Na_2HPO_4 \cdot 12H_2O$. These two solutions were mixed in equal parts when required for use.

Certain precautions must be observed in preparing dilutors. Only water that has been distilled in glass vessels should be used, and when filling ampoules the dilutor should not come in contact with rubber tubing.

The dilutor GTC was filtered through Whatman No. 40 paper before filling into ampoules. Neither solution of GPS 2 was filtered. The dilutors were filled into glass ampoules, which were sterilized for 20 minutes on 3 successive days. Both dilutors appeared to keep indefinitely.

Storage of sperm.—The following method was used for the storage of bull sperm. The sperm was diluted with one or two volumes of dilutor and transferred to a small test-tube, which was filled with medicinal paraffin and corked, and the cork was sealed with paraffin wax. The tube was wrapped in cotton-wool and placed in a Thermos flask containing water at 10° C. As little time as possible was lost between collecting the sperm and placing it in the flask. When sperm was to be used the test-tube was removed from the flask and allowed to stand at room-temperature for about 15 minutes before use. It was then examined microscopically for motility, and only specimens of sperm showing a high degree of motility, comparable with that of a fresh specimen, were used.

Results

Cattle.—A summary of the available results with cattle is given in Table 1. The conceptions for the Experimental Station are based on actual calvings, and for the other two farms on the cows which had not returned to the bull by October 1937.

TABLE 1. *Results with Cattle*

Farm	*No. of cows*	*Conceptions*		*Period of insemination*
		No.	Per cent.	
Expt. Station	90	69	76·6	10.i.36–21.xii.36
Farm 1	95	82	86·3	12.i.37–23.iii.37
Farm 2	258	148	57·3	17.i.37–6.iii.37
Total . .	443	299	67·5	

The percentages of conceptions on the Experimental Station (76·6) and Farm 1 (86·3) are equal or almost equal to the conceptions that result from natural service.

Of 197 cows inseminated once with undiluted sperm, 134 conceived (58·4 per cent.) but the percentage varied on the different farms from 40 on the Experimental Station to 73·1 on Farm 1. Results with diluted sperm were very similar: of 123 cows inseminated with sperm diluted ×2, 62 (50·4 per cent.) conceived, and of 105 cows inseminated with sperm diluted ×4, 56 (53·6 per cent.) conceived. A few experiments have been made with stored sperm. Thirteen cows were inseminated with sperm stored 6–8 hours and 6 conceived (46·1 per cent.); 43 with sperm stored 24 hours and 19 conceived (44·2 per cent.); and 2 (out of 5) cows conceived with sperm stored for 40 hours.

Sheep.—The results that have been obtained with sheep are given in Table 2.

TABLE 2. *Results with Sheep*

Farm	*No. of ewes*	*Conceptions*		*No. of inseminations per ewe*	*Period of insemination*
		No.	Per cent.		
Expt. Station	202	150	74·3	1·7	18.xii.35–28.ii.37
	159	40	25·0	2·2	10.vi.36–19.viii.36
	462	366	79·2	3·6	5.iv.37–15.vi.37
Totals & aver.	823	556	59·5	2·5	
Farm 3	3,102	1,367	44·1	1·6	22.i.36–19.viii.36
	1,101	572	52·0	2·5	5.iv.37–15.vi.37
Totals & aver.	4,203	1,939	48·1	2·1	
Farm 4	716	545	76·1	2·1	30.xi.36–28.ii.37
Grand totals & aver.	5,742	3,040	61·2	2·2	

The above results are based on the actual lambings, except for the inseminations in April–June 1937 which are based on the number of

ewes that 'held'. Two pure-bred Merino rams during April to June 1937 provided sperm for 1,865 and 894 inseminations, of which 411 and 212 respectively were fertile. On Farm 4 the majority of lambs were obtained from one pure-bred Corriedale ram. Using sperm diluted × 8, approximately 20–50 per cent. of the inseminations were successful.

Discussion

An analysis of the breeding records of several herds of cattle in Kenya has been made (unpublished results). The breeding efficiency of a herd was based on the number of calves produced by a cow during the whole time she was in the herd as a breeding unit. From this analysis the Experimental Station herd had an 80 per cent. fertility, and Farm 1 a 90 per cent. fertility, both of these figures being higher than those from the artificial insemination. The comparison, however, is not strict, for it relates fertility over a number of years with fertility over a much shorter period. Miller and Graves [12] based their analysis of the breeding efficiency of a herd of registered Friesians on the percentage of females actually bred that conceived, and found that the breeding efficiency was 86·3 per cent. The results of artificial insemination on Farm 1 are thus as good as those obtained by normal service in that herd. The somewhat poorer results with the Experimental Station herd are held to be due partly to inexperience of the method (this was the first herd to be inseminated) and partly to the herd containing a number of heifers (that had not been served at the normal time owing to poor condition consequent on drought) which are known to be more difficult to get in calf than cows [7].

The average number of inseminations per conception on the Experimental Station, Farm 1, and Farm 2, was 1·9, 1·4, and 2·1, respectively. The average number of services required for conception in a number of grade herds in Kenya is 3·6: on the Experimental Station 1·6 services were required for conception, and, on Farm 1, 6·9 (this herd contained a number of sterile bulls). The average number of services required for conception varies in different herds. Miller and Graves found that 2·8 were required and Knoop and Hayden [13] 1·87 and 1·53 in Holstein and Jerseys, respectively. The average for a number of American herds is 1·9. The number of inseminations required for conception thus compares quite favourably with the number of services required.

Excellent results have been obtained from artificial insemination of cattle in Russia and the percentage of 'settling' from this method of impregnation is as good as or better than from normal service.

In order to obtain the maximum benefit from artificial insemination of cattle it will be necessary on a large farm to transport sperm from one part to another to save cows walking long distances, and also from one farm to another. This involves the provision of a suitable method for preserving sperm. So far, 3 days is the longest period that sperm has retained its fertility outside the body (Walton). The fertility of sperm stored for longer than 40 hours has not been tested by the author, but there would seem to be no difficulty in keeping sperm alive and fertile for at least 24 hours.

Much work remains to be done on the optimum time for the introduction of sperm into the cervix of the cow. The optimum time depends on the relationship between the time of ovulation and the effective period of survival of sperm in the female genital tract. Ovulation in the cow occurs 24–48 hours after the beginning of heat [14], and it is said that sperm survive in the genital tract of the cow for 24 hours [15] and 15 hours [16]. The failure of a comparatively large number of cows to conceive after a single insemination or service is therefore probably due to the introduction of sperm into the female genital tract too early during heat. Two inseminations during a single heat-period have given much better results than a single insemination, only 10 per cent. of cows coming on heat again (Andreev), and this procedure is also recommended by Kirillov. Parsutin and Verevkina [17] found that the most favourable time for insemination was 18 hours after the onset of heat. Although grade cows in Kenya remain on heat for a much shorter period than cows in temperate climates, about 40 per cent. return to the bull either after insemination or after a single service by a fertile bull, and it would therefore appear that two inseminations during one heat-period (or the last insemination 18 hours after the onset of heat) would be advantageous.

Various aspects of artificial insemination of sheep have been discussed recently [7]. The view then expressed that a single insemination during one heat-period would probably be adequate now appears to require modification. It is believed that the relatively poorer results with sheep may be due to two factors: (1) seasonal changes in fertility of rams, and (2) introduction of sperm into the cervix of the ewe at an inopportune time. Seasonal changes have been noted in rams by McKenzie [18], in that mating ability and sperm production were at an optimum during the normal breeding-season and at a minimum during the summer months. Temperature is probably one of the main factors to bring about such seasonal changes, for it is well known that spermatogenesis is adversely affected by increased temperature. The possible effects of seasonal changes in environmental conditions, and particularly the effect of seasonal changes in temperature on the testes of rams in Kenya, require investigation if the best results from artificial insemination are to be obtained.

A single service during a heat-period in the ewe has been found to result in about 50 per cent. of conceptions (unpublished results), and a similar figure has been obtained from single inseminations; but two services during a single heat-period, with an interval of approximately 6 hours between them, raises the percentage of conceptions considerably. Moreover, of 197 ewes that were inseminated twice during a single heat-period at a 24-hourly interval, all conceived. It is therefore believed that two or more inseminations during a heat-period will not only give a better percentage of conceptions but will also shorten the breeding season.

It has been noted that there is a minimum period of approximately 25 hours after the onset of heat before ovulation occurs, irrespective of the duration of heat [19]. When heat lasts longer than approximately 26 hours, ovulation appears to take place very shortly after the end of

heat. When ewes are picked out for insemination once daily, the longer they remain on heat the longer will be the interval between insemination and ovulation, and hence a smaller chance of conception. It has been noted that the average duration of heat in grade Merino ewes was longer in 1937 than in 1936 (unpublished results), and this difference may be to some extent responsible for the lower percentage of conceptions during April to June, 1937.

The results, nevertheless, are sufficiently promising to suggest that artificial insemination may be of considerable value to the sheep-farmer in Kenya and other tropical countries, and this belief is strengthened by the fact that the inseminations on Farm 4 were carried out entirely by the farmer himself with only occasional supervision.

Practical Applications

Although further work is needed to raise the percentage of conceptions from artificial insemination of cattle and sheep, the main problem is now one of organization. Except on very large cattle-farms, it is not at present possible to get the maximum use from a bull. To do this would require the restriction of insemination to a breeding-season and the storage of sperm. A vigorous adult bull should be quite capable of performing three services a week. Therefore, in a large herd where cows are coming on heat every day, a minimum of three bulls would be required. This number of bulls could probably be reduced if stored sperm could be used.

At present, apart from the Experimental Station, artificial insemination is being carried out by the farmer himself on four cattle farms in Kenya, where the total number of cows is approximately 3,000. Quite satisfactory results will probably be obtained on these farms. One of the main problems, however, is to regulate the services of bulls. On the two farms where insemination has been practised for the past ten months, young bulls were mainly used, and in both cases the bulls were overworked, so that the percentage of conceptions was reduced.

The main advantages of artificial insemination of cattle do not require elaboration, but there are certain aspects which apply perhaps more particularly to a country like Kenya. In the first place there are several herds of cattle in the country, numbering hundreds of cows, for which a large number of bulls is required. It is on such farms that most use can be made of artificial insemination. The number of bulls could be considerably reduced and consequently a better type of bull could be introduced. On one farm in Kenya, where formerly 40 or more bulls were required, 11 are now being used for artificial insemination. It is probable that this number will be reduced when more experience of the method is gained, and when better sperm-producers are available. On another farm, 4 bulls are being used to inseminate approximately 800 cows.

In Kenya there is a very high incidence of sterility in bulls, which is thought to be mainly due to an infection acquired from the cow. Bulls in ordinary use in herds run a considerable risk of picking up this infection, and when pure-bred bulls are used the loss may be heavy. This

form of sterility can be avoided entirely if artificial insemination alone is used. The role of artificial insemination in combating Trichomonas infection in cattle has been pointed out by Fuchs [20] and Feiling [21]. On the farm which runs over 40 bulls fully half of them were slaughtered owing to sterility. Apart from the expense of purchasing new bulls, it is doubtful if they could be replaced in Kenya. The problem would have been an extremely serious one if artificial insemination had not been used. It has been found that of all the bulls tested 35 per cent. are sterile and others are of reduced fertility (unpublished results). These figures alone provide ample justification for the use of artificial insemination in European-owned herds of cattle in Kenya.

The advantages of artificial insemination of cattle are not, however, restricted to European-owned herds. It may prove of equal or even greater value with Native cattle. In certain districts a cross between Zebu cows and imported bulls may prove useful. An experiment of this nature is contemplated in a district free of East Coast fever in the Masai Reserve. Unless, however, the plane of nutrition is unusually favourable, it would seem probable that the best results would be obtained by not attempting to go beyond the first cross. Apart from imported bulls of European breeds, the introduction of, say, the Afrikander, which is more akin to the local cattle, might prove a suitable type for beef and draught purposes. However, it is more likely that, in general, better results would be obtained by using selected Zebu bulls. The supply of such bulls from Veterinary Training Centres in Kenya should become increasingly available, and the extensive use of them in Native Reserves by means of artificial insemination, combined with castration of scrub bulls, should be capable of effecting a radical improvement in Native cattle.

The possibilities of using artificial insemination for sheep are perhaps even greater. In Kenya 3 per cent. is the usual proportion of rams in European-owned flocks. In the larger herds, numbering several thousands of ewes, it is not possible to provide this number of pure-bred rams, and consequently a large number of grade rams has to be used. If artificial insemination were used, these rams could be eliminated and the number of pure-bred rams required could be considerably reduced. In the Experimental Station flock, numbering approximately 900 ewes, formerly 18 rams—11 pure-breds and 7 'grades'—were used. In the last two seasons these ewes have been inseminated with sperm from 2 or 3 rams, and no attempt has been made to inseminate the maximum number of ewes with one sire. This present year (1938) two pure-bred Merino rams have successfully impregnated 411 and 212 ewes, and in a grade Corriedale flock of over 700 ewes most of the conceptions were due to one ram.

There are large areas in Native Reserves in Kenya that appear to be eminently suited to sheep-farming. The successful establishment of improved types of sheep of different breeds in different districts would provide the native with an income from wool, and mutton for consumption. A Merino crossbred, for example, would probably thrive in the Masai Reserve, and in the Northern Frontier Province, and in other Reserves of higher rainfall, use might be made of the Romney Marsh.

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The general aspect of the application of artificial insemination to livestock-breeding in Kenya is twofold. In the Native Reserves it must be carried out by Government; and in the settled areas the farmer will have to apply it himself. The technique of artificial insemination provides no great difficulties, and, provided full attention is paid to detail, satisfactory results should be obtained. The method, however, necessarily demands more of the farmer than does the practice of allowing the bull to serve the cow naturally, and it will be interesting to see to what extent artificial insemination is adopted by the farmer, and whether he will continue to employ it.

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XUM

A NEW SERVICE-CRATE

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WITH PLATE 10

ALTHOUGH this service-crate has several uses it was designed originally as an aid in the technique of artificial insemination. For the regular collection of semen, either for dispatch for insemination or for periodic examination of a bull's fertility, it is very desirable to be independent of a cow in oestrum; such dependence, especially in small herds, makes a regular plan of work impossible.

We have found that with surprisingly little training a bull will mount a cow that is not in oestrum so long as she stands, or can be made to stand steady. Our normal procedure has been to have the crate in the surroundings which the bull has come to associate with normal service. This is not always necessary, however, for the service-crate with a non-oestrous cow has been successful with bulls unused to any handling and in completely strange surroundings; and with young bulls at service for the first time.

The crate is held firmly to the ground by 6 holding-down irons 1½ ft. long, 2 at the front and 2 on each side. (Where the crate is to be a permanent fixture it may, of course, be bolted down on concrete.) The yoke is a shortened 'Loudon-King' stall-fitting, and in it the cow is securely held. The T-iron used in construction contributes strength without giving undue weight to the crate. By lifting and balancing it in the proper place one man can move it. The dimensions given in the plan are suitable for cows of the Shorthorn, Devon, and Friesian breeds, but for such breeds as the Ayrshire, Jersey, and Guernsey, suitable reductions in height and length require to be made. To make the crate more adaptable to cows with necks of different lengths we suggest an improvement in design to that shown in the original plan; namely that the chain holding the bottom of the neck-yoke be attached to a clamp sliding on the projecting strut to which it can be bolted at any suitable length. The cost of the crate should be between £5 and £10, according to the amount of material (e.g. wood or stall-fitting) available.

When a collection of semen is to be made the bull mounts the cow in the crate. His penis is directed into the artificial vagina on the cow's flank and into this he ejaculates. There is no evidence that such an ejaculate is in any way different from that collected by the use of a cow in oestrum. We have used this method for 450 semen collections from 25 bulls of four different breeds. Only one old bull, extremely slow and particular about a normal service, has so far failed to respond.

Other uses to which the crate can be put are, for example, in aiding the normal service of a very restless cow, or in the insemination or blood-sampling of such an animal; and in the service of young heifers by a heavy bull. (A bundle of straw under the heifer's fore-feet will bring her up to the yoke-height.) Before the bull puts all his weight on the heifer he finds himself with his feet on the foot-rests at the side.

(*Received February 8, 1938*)

SERVICE — CRATE.

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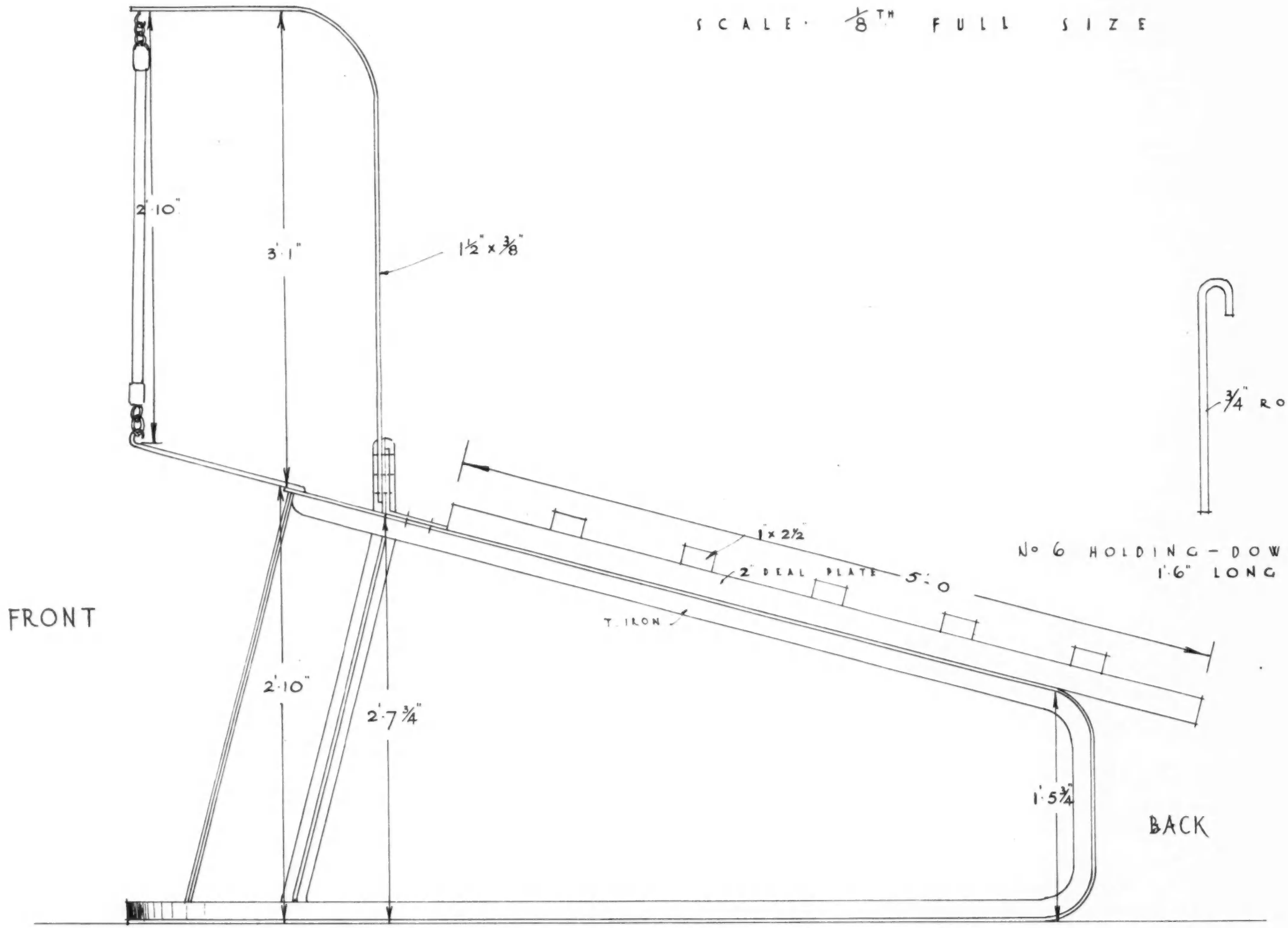

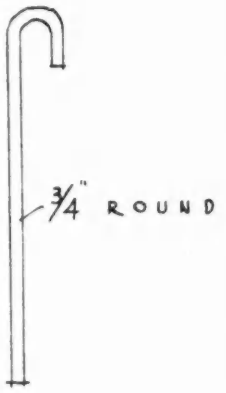

No 6 HOLDING-DOWN IRO
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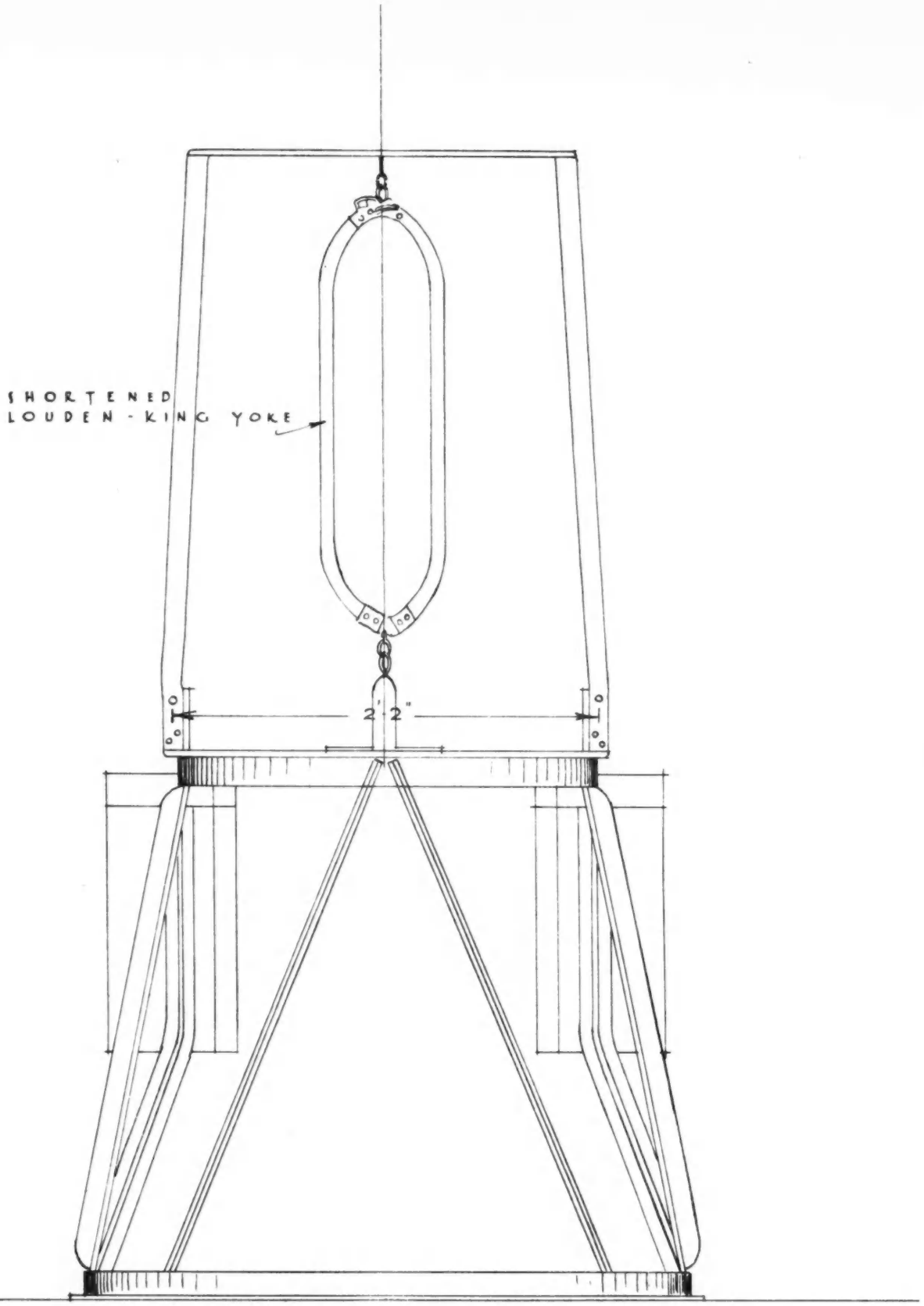

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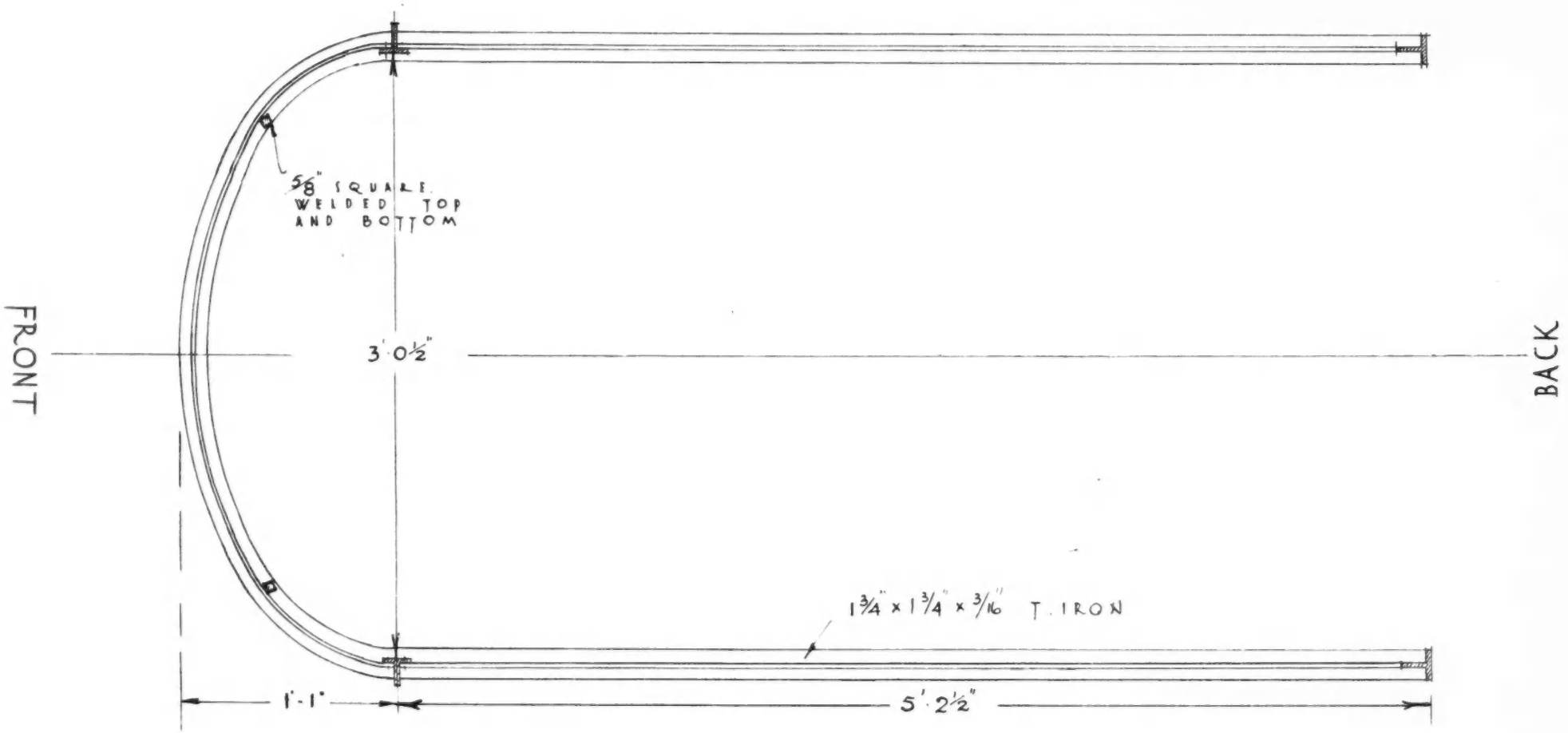

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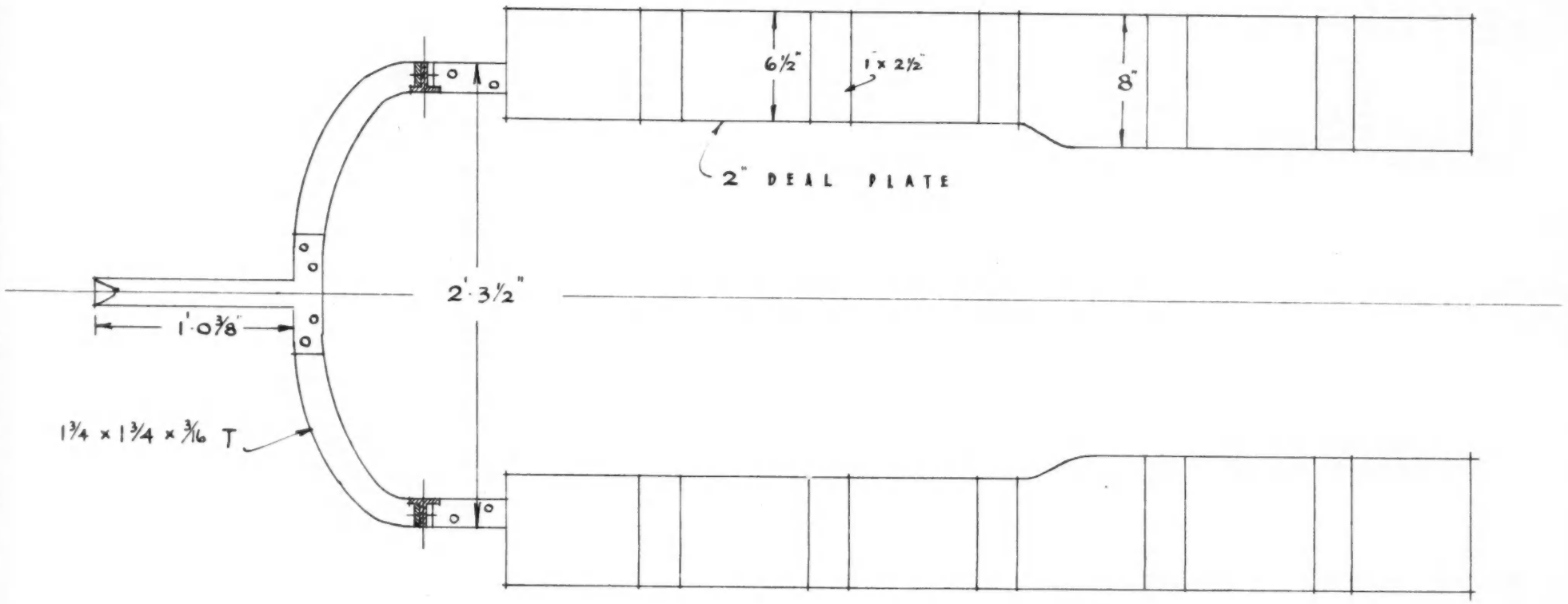

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INVESTIGATIONS ON BLACK-ARM DISEASE OF COTTON UNDER FIELD CONDITIONS

III. THE MODE OF INFECTION OF THE NEWLY PLANTED CROP

F. W. ANDREWS

(*Plant Pathologist, Agricultural Research Service, Anglo-Egyptian Sudan Government*)

THE first paper of this series [1] showed that the principal source of infection of the new crop in the established cotton-land of the Gezira was the cotton debris on the previous season's land immediately adjacent, and a highly significant correlation was established between the severity of the infection and the earliness of the sowing-date, in so far as the cotton plants would be subjected to more rain-borne infection. Delayed sowing, however, is not a practicable means of control, since the crop suffers thereby in quality. It was demonstrated in the second paper [2] that infection from infective cotton debris was very considerably diminished when the debris was flooded, whereas the rainfall alone was insufficient to render the debris innocuous. It was found also that flooding reduced the number of volunteer cotton seedlings on old cotton-land and eliminated the characteristic localized infection of the adjacent new crop. The sporadic infection which persisted was ascribed to debris carried on to the new land before the new crop was sown. As a control measure, flooding is practicable in small areas only, and may then for greater safety be combined with later sowing-date.

In the present paper infected volunteer seedlings are shown to be much more dangerous than infected cotton debris. Screens of Sorghum or Pigeon Pea (*Cajanus indicus* Spreng.) were found most efficacious in preventing rain-borne spread of Black Arm. Attention was finally directed to the means whereby infection is spread into areas at a considerable distance from land previously carrying cotton. Outbreaks of the disease in land newly brought under irrigation seemed to show that the sources of infection were more pervasive than was indicated by our observations. A careful watch was therefore kept on two such areas, and it was found that apart from the lighter debris carried by 'dust devils' (small-scale cyclonic wind-storms), much plant material is introduced by the natives. This, it may safely be conjectured, is the source of the sporadic infection occurring in new land.

Mode of Infection of the New Crop in an Established Cotton Area

An experiment was designed in which hedges, 5 metres thick, of early sown sorghum separated 20 narrow strips of land running NE. and SW. At the NE. end of each strip was an infector plot containing infected debris or infected seedlings. The strong driving rains coming from the NE. would, it was hoped, carry infection from this material to observation plots of cotton situated 10 m. away in a SW. direction from the

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infector plots. This lay-out provided 4 replicates of the following infector treatments:

A. The ground was lightly strewn with infected cotton debris (exclusive of seed-cotton).
B. The same as A, except that the debris was later swept off the ground to imitate an attempt to clean the land.
C. The ground was spread with infected debris, and 1 lb. of bleaching powder was spread on the land, and the plot flooded for one day.
D. The same as C, but the flooding was continued for 3 days.
E. A few widely scattered cotton seedlings were grown in the plots and infected with Black Arm by spraying them with a suspension of the organism obtained by soaking infective cotton debris in distilled water for 1 hour.

The sorghum hedges were sown on May 20, 1935, and the whole of the land of the experiment was heavily flooded on June 4–5, to ensure that the ground contained no infective material. The Black-Arm infective debris was laid on the infector plots at the end of June, and the flooding treatments (plots C and D) were carried out immediately following the laying of the debris. The cotton seed on the E plots was sown on August 2, and sprayed on August 8 and August 26. No attempt was made to remove the weeds on the infector plots. Owing to the poor development of the hedges, it was not considered advisible to sow the observation plots until August 25, the plots having been heavily flooded again on August 17 to ensure the destruction of any extraneous cotton debris blown on to the land.

The seed used was Egyptian Sakel (imported direct from Egypt), and before sowing it was delinted for 15 minutes in concentrated sulphuric acid, and then dusted with the proprietary bactericide called Abavit B, at the rate of one part of bactericide to 150 parts of seed.

During the whole of September the rains were either insufficient in amount or not in the right direction to cause an infection of the control cotton plants. At the beginning of October, however, a suitable driving rain-storm occurred (a rain-storm which was sufficiently widespread to cause a severe outbreak of the disease in the cotton of the Gezira as a whole), and a count of the resultant infected plants in the observation cotton plots demonstrated conclusively that the infected cotton seedlings (contained in the E infector plots) were responsible for the bulk of the infection of the crop alongside.

The following table shows the percentage of infected plants present on October 12 and 13, i.e. 10 days after the storm; each plot contained about 2,500 cotton seedlings.

Fig. 1 shows the distribution of the diseased plants in the cotton plots. Points of especial interest are:

1. The source of the most intense outbreak of the disease on the control cotton was the infected seedlings.
2. The number of infected plants found in the cotton opposite the infected debris plots (A, B, C, and D plots) was too small to show

any significant differences in treatment, or to indicate that infective debris, when surrounded on the ground by weeds, would cause a serious outbreak of the disease in cotton plants situated at least 10 m. away from it.

3. In the severely infected cotton plots down-wind of the E infector plots, a concentration of the disease is noticed on the side of the plot *nearest* the E plots, giving in miniature the distribution of the disease so common in the plants of the cotton howashas of the Gezira cotton area [1].

Treatment	*Observation plot numbers*				*Plants infected. Per cent.*				*Average*
A	1	7	12	18	0·63	1·30	0·24	0·50	0·67
B	3	9	11	19	0·42	0·55	0·14	0·17	0·32
C	4	8	15	20	0·81	0·06	1·09	0·94	1·22
D	5	10	13	17	0·28	Nil	0·56	1·00	0·46
E	2	6	14	16	42·10	20·5	20·00	11·10	23·40

4. The distribution of the diseased plants (Fig. 1) shows how outstandingly efficient were the sorghum hedges in preventing the carry-over of the disease from a severely infected plot to a lightly infected one laterally adjacent to it, despite the fact that much of the sorghum had made very poor growth.

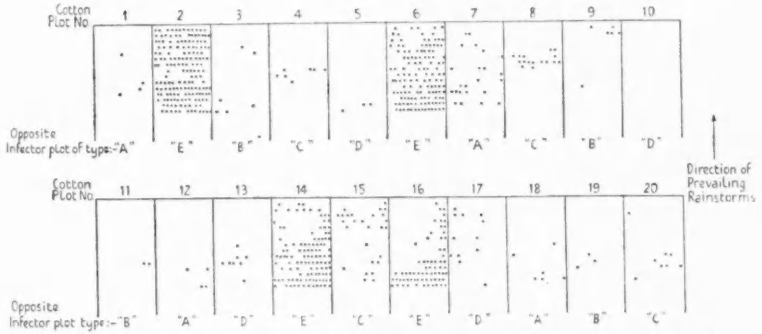
Cotton Plot No
1 2 3 4 5 6 7 8 9 10
Opposite Infector plot of type:-"A" "E" "B" "C" "D" "E" "A" "C" "B" "D"
Direction of Prevailing Rainstorms
Cotton Plot No
11 12 13 14 15 16 17 18 19 20
Opposite Infector plot type:-"B" "A" "D" "E" "C" "E" "D" "A" "B" "C"

FIG. 1. Showing distribution of infected plants in the observation cotton plots. (*In the experiment the plots were in a continuous row.*)

The effectiveness of tall closely sown sorghum plants as a screen against rain-borne infection has been proved repeatedly on the Gezira Research Farm, where it is now a standard practice to sow early hedges of sorghum where possible between the new and the old cotton-land. Other tall thickly growing crops might also be effective in acting as a screen; we have had considerable success with hedges of pigeon pea. Sorghum is used on the Gezira Research Farm because it is the principal grain crop of the Sudan, and is included in the normal crop-rotation.

Water is available for irrigation on the Research Farm at any time of the year, and thus the sorghum can be sown sufficiently early to raise an effective screen by the time the new cotton crop is above ground. In the

Gezira cotton area, as a whole, this is not possible under the existing Nile-water agreement with Egypt, which results in no canal water being available (other than for domestic purposes) between April 15 and July 15. A sorghum screen should be sown towards the end of June to reach a sufficient height to provide adequate protection for a cotton crop sown from August 5. In years of heavy rainfall it would, of course, be possible to grow the screens on rain alone, but the rainfall in the Gezira plain is so variable and uncertain that no reliance can be placed on it. The growing of an early sorghum or other crop to form an effective screen against rain-borne infection is thus not practicable over the Gezira cotton area.

The Viability of Fallen Cotton Seed

It has been estimated that possibly 20 lb. per acre of soiled seed-cotton remained on the ground at the end of the picking season, i.e. at the middle of May. Such infected seedlings as will arise from it during the coming rains are a potential menace to the new crop. It was inconceivable that all such seed remained viable until the arrival of the rains in July, and a small experiment was accordingly designed to estimate just how much of it survived to produce seedlings when the rainfall was sufficient. The details of the experiment were as follows:

About $\frac{1}{13}$th acre of uncultivated land on the Research Farm was divided into 12 equal plots. Ridges were made in each plot, and were then flattened to make the plots equivalent, as far as possible, to the cotton-land at the end of the picking season. All the plots were flooded on March 18, 1934, to make the water-content of the soil to a level approximate to that of the cotton-land. The cotton seeds in locks of seed-cotton were counted without opening out the locks, and a quantity equivalent to 800 seeds (representing, roughly, 37 lb. per acre) was distributed evenly over each plot on March 31. The seed-cotton was then trodden into the soil and *very* lightly covered with soil to prevent its removal by strong winds. A germination test on the seed-cotton revealed that it contained 75 per cent. viable seed; thus each plot actually contained 600 viable seeds. On May 5, *six* of the twelve plots were given a flooding equivalent to that practised on the Research Farm, on cotton-land, as an anti-Black-Arm measure at the end of the picking season. The results and advantages of this treatment have been described [2]. After this flooding, and after each rainfall, the germinated seed was counted per plot, a seed being considered as germinated when the cotyledons had opened. The plots were not weeded. The results (see next page) were obtained by July 24, no further germination occurring after that date.

There is no considerable difference in germination between the plots that were subjected to rain plus flooding and those that received rain only. This indicates that only about 25 per cent. of the seeds survived weathering for 6 weeks before the flooding on May 15. No rain fell (or normally falls to more than a minor extent) in this very hot period of the year. The seed subjected to rain only did not germinate actively until after June 24, and thus underwent weathering for a further 5 weeks; this fact would account for the lower percentage germination of this seed.

Fig. 2 (p. 212) shows the relation of rainfall to total seeds germinated. The slight germination in the non-flooded plots from May 20 to May 30 was due to seepage from the flooded plots. The flooding was equivalent, in actual quantity, to 150–180 mm. of rain. That 208 mm. of scattered rainfall were required to produce a roughly equivalent germination is not surprising, since counts were made only on seed that had produced *seedlings with open cotyledons*. It is conceivable that some seeds in the non-flooded plots germinated, but the 'rain of germination' and subsequent rains were either insufficient or too wide-spaced in time to allow the seed to produce a seedling: the germinated seed would thus wither and die.

Flooded plots			*Non-flooded plots*		
Plot no.	*Total seedlings germinated*	*Percentage germination*	*Plot no.*	*Total seedlings germinated*	*Percentage germination*
1	206	34·3	3	161	26·8
2	211	35·1	4	184	30·6
5	162	27·0	7	142	23·6
6	153	25·6	8	117	19·5
9	141	23·5	11	135	22·5
10	153	25·6	12	123	20·9
Averages	171	28·5	..	143·6	23·9

At the end of the experiment the remaining seed-cotton was collected and examined. No viable seeds were found; most of them had been bored by insects, and in the rest the structure inside the seed-coat was completely dry and withered.

Assuming from the above results that at the most only one-quarter of the seeds germinates during the rains, it still leaves us with a possible 5 lb. of viable seed-cotton per acre on the ground. Possibly only a *very* small proportion of these seeds give rise to seedlings inherently infected; a greater proportion of the seedlings are probably infected by rain-splash from infected cotton debris lying near by. The potentialities of this disease-infected material are, however, considerable, and in actual practice an attempt is made by the tenants at the end of the picking season to clean the cotton-land both from seed-cotton and other cotton residues after the plants have been pulled out and burnt. That the remaining material on the land is still dangerous is shown by the severe localized attacks that occasionally occur and can be traced to this cause.

Weeding of cotton seedlings from the old land before the new crop is sown seems an obvious method of control, but to do this with the thoroughness necessary to prevent an attack of Black Arm would be impracticable in the Gezira cotton area. At the sowing-time, all tenants and their families are busily engaged in weeding the new land in preparation for the sowing: the thorough weeding of the old land in addition to the new would be an impossible task, and would seriously delay the sowing of the new crop.

Mode of Entrance of Black Arm into an Area not previously sown to Cotton

It was expected that the source of infection cited above would be absent from land that had not grown cotton previously; nevertheless, severe outbreaks of the disease occurred in such areas, and during 1935 and 1936 the staff was concentrated on new land in attempts to elucidate the cause of this anomaly.

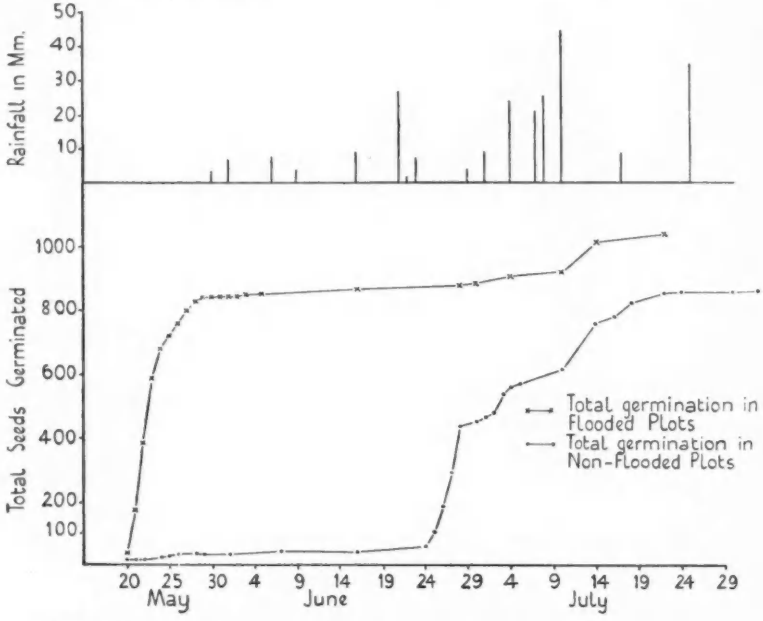

FIG. 2. Germination of seeds enclosed in locks of fallen seed-cotton under flooding and rainfall.

1. *Debeiba Block, 1935*

The work during 1935 was of necessity preliminary and exploratory, and an area approximately rectangular, called Debeiba Block, was chosen for the investigation; it was bounded on two sides by old cotton-land, and was due to be planted with cotton for the 1935–6 season.

The work of digging the canals and water-channels for the new area was nearly completed by April 1935. A cursory inspection of the land even at that early date, showed that seed-cotton and infected cotton leaves were already lying on the ground. Although the quantity of this cotton material naturally varied considerably from place to place, it was evident before the 1935–6 cotton crop was sown at the beginning of August that an outbreak of the disease was to be expected in this area. The disease was discovered first in the *centre* of the Block, and thereafter reports of new infections were received with increasing rapidity. A

survey of the area, made to locate the position of points of earliest infection, gave the following results:

(*a*) Cotton debris of all kinds was found scattered in all parts of the block, even in fields most distant from the previous season's cotton-land.

(*b*) The places of earliest outbreak were likewise scattered through the area: there was no tendency to concentrate in those places where the new area adjoined old cotton-land. It seemed evident, therefore, that the main infection had arisen from this scattered debris and was not the result of a 'blow-over' from the adjoining old cotton-land.

(*c*) Efforts to decide the principal mode of transport of this cotton debris into the new area indicated that the natives living in the villages of the area were mainly responsible. Seed-cotton was found in most villages, and in two of the villages cotton sticks were being used as fuel.

From the results of this preliminary investigation a scheme was devised in 1936 to determine more accurately the source of this debris and possible means of control.

Two areas were chosen for these investigations.

The first area, known as the Wad Hilal Extension (Fig. 3), comprised land lying west of the Tabat Branch Canal. The land commanded by three canals, viz. Tukl, Tukl North, and Hegeleia, was chosen as the observational area. This area was bounded on the north by further new cotton-land, on the south by uncultivated land (i.e. non-irrigated, but used for rain-grown sorghum) containing the large village El Tukl, on the west by uncultivated land, and on the east by a narrow belt of rain-grown sorghum immediately alongside the Tabat Branch Canal. East of the Tabat Branch Canal was old cotton-land. The observational area was thus adequately protected on the west, north, and south sides, and on the east a sorghum belt about 200 m. wide, plus the width of the Tabat Canal (about 35 m.), separated it from the previous season's cotton-land.

The second area known as Fawar was situated at the NW. extremity of the land under the Gezira irrigation scheme, and was about $3\frac{1}{2}$ miles from the nearest old cotton-land.

2. *Wad Hilal Observational Area, 1936*

It will be seen from the map (Fig. 3) that this area is only accessible from the east by crossing the Tabat Canal, when full, at either of the two bridges, one opposite El Tukl village and one opposite Wad Rabia village. As these two bridges represented possible points of danger, a police post was established in January 1936 at each of these bridges, and instructions were given to prevent any seed-cotton or other cotton material being taken into the area. The police posts were of course effective only while the canal was full; when, at the end of the cotton season, the water-level was lowered, and wading across the canal was possible, very little check could be kept on the amount of cotton material

entering the new land. The map shows that the new cotton-land nearest to this old land was No. 12 Hegeleiga Canal; the remaining new cotton-land being over a mile and a half away, so that the risk of rain-borne infection from this old land was practically negligible. This Wad Hilal observational area therefore consisted of new cotton-land protected as far as possible from any rain-carried infection.

From February 1936 onwards observers were stationed in the new area with instructions to make periodic inspections of the land, and to collect and record the position, type, and date of finding, of any cotton

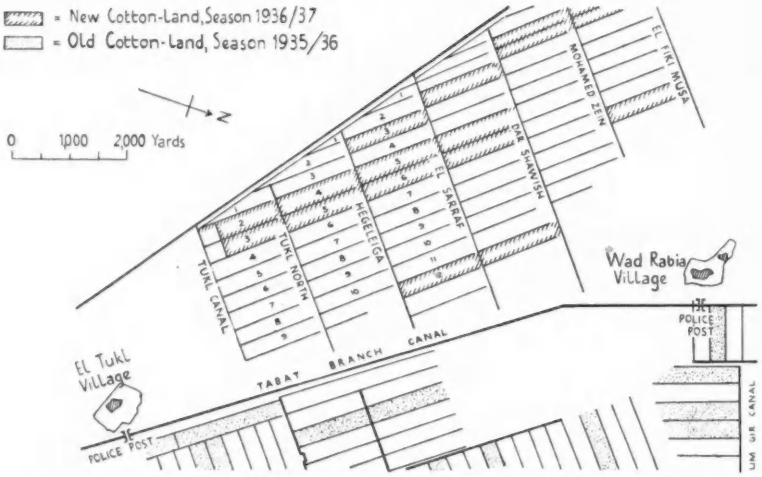

FIG. 3. Map showing lay-out of new and old cotton-land in Wad Hilal area.

debris. These inspections were continued until the cotton crop was sown at the beginning of August. Sowing of No. 12 Hegeleiga Canal was delayed until August 19, as it was assumed that, being nearest the old cotton-land, the earliest infections would be likely to appear there. After the cotton was sown, routine examination of the cotton plants was made for the presence of Black-Arm disease. The following results were obtained:

(*a*) *Cotton Debris*.—Fig. 4 shows the distribution of the debris found in the area. It will be noticed that from April 5, 1936, cotton debris of all kinds was found scattered throughout the area. To take each type of debris separately:

(1) *Leaf-debris* occurred generally through the area, though not all of it was infected with the disease. General observations confirm the fact that leaf-debris is principally carried by strong winds, of which the whirling 'dust devils' are probably the chief offenders. It has, however, also been shown by experiment that the disease in leaf-debris does not remain viable for very long when exposed to the sun and rains of the

pre-sowing period. This form of debris is thus not considered to be an important source of the disease.

(2) *Seed-cotton* was also widely distributed, and its occurrence must be attributed in great part to introduction by the natives. It was evident early on in the pre-sowing observational work that, owing to the difficulties of the task, not all cotton material was being prevented by the police posts from entering the area. Seed-cotton was often found at the camping places of the gangs that were digging the smaller water-channels, and as these were also being dug in the new area to the north

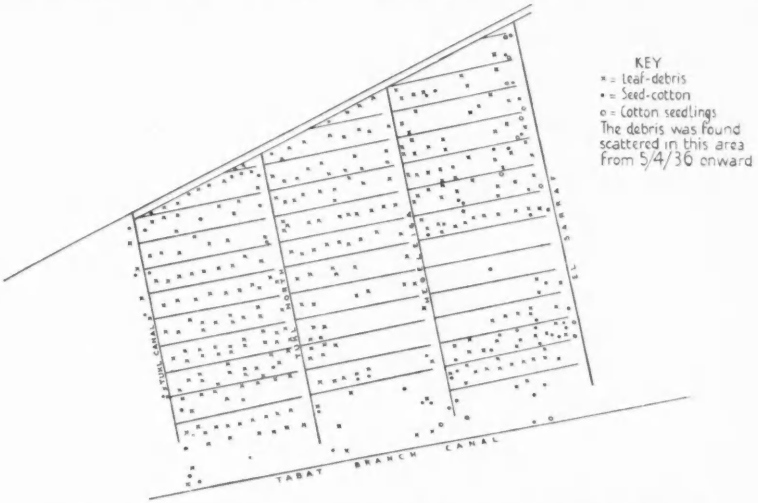
KEY
× = Leaf-debris
• = Seed-cotton
o = Cotton seedlings
The debris was found scattered in this area from 5/4/36 onward
TABAT BRANCH CANAL

FIG. 4. Map showing distribution of cotton remains over Wad Hilal observational area.

of the observational area, there was nothing to prevent the introduction of seed-cotton from this north side. Such seed-cotton as was found was submitted to Mr. H. E. King, Plant Breeder, Sudan Government, to decide if it was of the same type as that grown in the adjacent old cotton-land. No sample was found that could not have come from the previous season's crop, and he suggested that 'a likely source of all these samples is the dirty locks picked out of the Gezira crop by tenants when cleaning and picking their cotton'.

(3) *Cotton seeds*. Small collections of cotton *seeds* were occasionally found near the camping sites of the labour gangs; these must have come from seed-cotton introduced by these gangs. It is a general practice among the natives of the Gezira cotton area to make thread from the cotton lint. The practice is illegal, but that it is done surreptitiously is shown by the presence of this hand-ginned seed on the ground. Apart from such seed acting as a carry-over of the Pink Bollworm from one season to another, it is also a very grave danger to the coming crop in that some of it may be infected with Black Arm and produce diseased

seedlings. Ginned cotton seed on the cotton-*land* is more likely to be found in new areas where villages may not occur: in the old cotton-growing areas the thread would undoubtedly be made in the houses of the villages, and the serious danger occurs that this ginned, possibly infected, seed may become mixed in the tenants' houses with the disinfected sowing-seed of the coming season.

(4) *Cotton seedlings*. That the cotton seed described in (3) is a very positive danger was shown by the discovery from July 5 onwards of cotton seedlings growing in the new cotton-land, i.e. the land that would be sown with cotton about a month later. The sowing-seed for the 1936–7 season was not issued until the very end of July, so these seedlings must have arisen from rain-germinated seed already present on the ground. None of the seedlings found were infected with Black Arm, but that was probably quite fortuitous and does not in any way lessen their significance as a possible factor in the incidence of the disease.

(5) *Old cotton stalks* were distributed about the area and appeared to have been occasionally used as fuel by the digging gangs. After infected seedlings, infected old cotton stalks have been found to be the most potent source of Black Arm, as the organism on the cotton plant appears to survive weathering longest when present on the stem.

(*b*) *Black-Arm infection of the new crop*.—The disease was first discovered in No. 5 Hegeleiga Canal on September 14 in cotton sown from August 1–5. The type of the infection, viz. 'an isolated heavy infection' [2], suggested that the source of the disease was infected debris. From this date onwards evidence of the disease was discovered in most of the cotton-fields under observation, except that no disease was found in No. 12 Hegeleiga Canal, which (as stated above) was not sown until August 19. The fact that the disease did not occur first in cotton of the same sowing-date nearest the old cotton-land indicates clearly that the disease was not due to rain-borne infection. The absence of the disease in No. 12 Hegeleiga Canal indicates strongly that the sowing-seed was free of the disease. It must be realized that in making observations on cotton plants in an area of this size (about 680 acres of sown cotton-land) an extremely large number of observers would have to be employed to ensure finding the disease at its *first* appearance. It is computed that there were at least 12 million cotton plants in this area. In actual practice certain selected areas, evenly distributed over the cotton-land, were put under observation, and even then it took some time to inspect the whole of the selected area. This undoubtedly accounts for the comparatively late finding of this first isolated heavily infected plant. The disease on this plant when found was probably about 3–4 weeks old.

Since the cotton debris, when found on this land, was removed, no relation between the position of the debris and the position of the earliest outbreaks of the disease was expected or found. The presence of the disease in the new cotton plants indicated, however, the practical impossibility of sufficiently cleaning a large area of cotton-land to ensure that no disease would appear in the area. When compared with adjacent new cotton-land on the north side, the observation area did appear to have less Black-Arm disease, but not sufficient was known of the cotton-

debris situation in the northern land to decide if the lesser amount of Black Arm was due to such cleaning as had been done on the observation area.

3. *Fawar Observational Area, 1936*

This area being situated some considerable distance from the previous season's cotton, no attempt was made by the use of police posts or other means to prevent the introduction of cotton debris. As in the Wad Hilal area, observers were distributed over this area some months before sowing-time, with instructions to collect and record the details of any cotton debris found.

Sowing of the new cotton-land did not begin until August 9, and the bulk of the cotton was sown by August 19. This area was thus somewhat later sown than that of Wad Hilal. After the sowing was begun, the observers were instructed to make periodic examinations of the young cotton plants to determine the position and date of the first outbreaks of Black Arm. The following results were obtained:

(*a*) *Cotton debris.*—The distribution of cotton debris over the Fawar area was similar to that of Wad Hilal. Seed-cotton was found, from the end of May, on the coming cotton-fields and lying around newly built villages, and had apparently been brought by incoming tenants and cotton pickers from the old land. It was also found near the sleeping places of gangs constructing the bridges of the new canals. Cotton-leaf debris was found scattered throughout the area, and, as in the Wad Hilal area, appeared to have been introduced by strong winds. No cotton seedlings were found growing in this area before the sowing of the new crop, and it is possible that the difference in rainfall in the two areas may account for their absence.

(*b*) *Black-Arm infection of the new crop.*—The disease was first reported in the area on September 21, the later date of appearance, as compared with Wad Hilal, being doubtless associated with the later sowing-date. This again was a case of an isolated heavily infected plant, and, from this date, reports were received of the presence of the Black Arm in other parts of the cotton-land. The disease was finally found scattered throughout the cotton-fields. The general severity of the disease was considerably less than that in Wad Hilal. This was doubtless due both to the later sowing-date and to the smaller amount of rain to which this area was subjected. From the date of sowing, the Fawar cotton plants received a total of 95 mm. of rain, whilst those in Wad Hilal received about 200 mm.

Conclusions

The observations have shown clearly the impossibility of raising disease-free cotton plants in the Gezira, even in a new area where cotton has not previously been grown. The sowing-seed in the areas under observation was free of the disease, and experiment has demonstrated that the bacteria in infected leaves cannot survive the weathering of the pre-sowing period. Widespread wind-blown debris is almost entirely

limited to leaves, and it therefore seems evident that the outbreaks of Black Arm that occurred must have been due to infective material introduced by humans. Without radical alterations in the habits of the natives themselves, it therefore seems impossible to ensure that cotton debris will not enter a new area and serve as an initial source of the Black Arm, which will later become perpetuated and infect in varying degree the crop of each succeeding season. The steps taken to exclude the disease in the Wad Hilal district represent the limit of any possible practical measures over a large area, yet they were obviously quite inadequate to prevent the disease attaining such proportions as would cause some loss in the cotton-yield. A renewed dissemination of cotton-plant material throughout the fields of the Gezira must obviously take place at the end of every picking season. In the Gezira no conceivable legislative measures would be likely to prevent the introduction and perpetuation of a disease so potent and easily disseminated as Black Arm, and if legislative measures were devised, their enforcement would be a practical impossibility over such a large area. While the natives persist in using cotton-plant materials for private purposes (a very natural proceeding), one cannot hope to keep any part of the Gezira free of the disease. Until it is possible to grow a strain of cotton resistant to the disease, all that can be done is to adopt such practical remedial measures as will ensure that the incidence and spread of the disease will be kept within reasonable bounds.

Acknowledgements

I have to acknowledge my indebtedness to Mr. M. A. Bailey, Director, Agricultural Research Service, Sudan Government, under whose direction these researches were carried out. I have also to thank Dr. H. Greene and Mr. O. W. Snow, both of this Service, for assistance in presentation of the data.

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RECENT BOTANICAL RESEARCHES IN CACAO

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A REVIEW of botanical investigations of cacao must begin with a definition of the material with which it deals, because much of the work to be mentioned has been done on a small section of the crop. Even within that section, research has scarcely proceeded beyond the stage of defining the lines along which knowledge is to be sought. A little straightforward selection from a mixed population, some progress in the technique of propagation, and a few rays of light on factors limiting yield are the main points to be noted. These, however, put us in a position to appreciate many horticultural problems that are bound to arise in the near future, and some discussion of them may be included to show the trend of improvement in one of the most important tree crops of the tropics.

The Material for Research

Various species and varieties of the genus *Theobroma* seem to have been utilized by the indigenous peoples of America, from Mexico to Peru, before the discovery of the continent by Europeans. The 'bean' was highly prized, and it is only reasonable to suppose that from very early times the natural distribution of varieties was extended by the agency of man. All races of cultivated cacao intercross readily, so far as is known, and whether originated or merely facilitated by human agency, interspecific mixture took place long ago. In some districts hybridization has obscured origins, whilst in others local races remain unmixed and specifically pure.

The number of species concerned cannot be stated, but following Pittier [1] we may recognize two of major importance. The first is *Theobroma Cacao* L., a name commonly applied to all cacao, but *sensu stricto* confined to one constituent only, that known to commerce when grown in a pure state as 'Venezuelan Criollo'. The pods of this species are long, distinctly pointed, deeply furrowed longitudinally, and warty, their colour being commonly dark red, sometimes yellow. The 'beans' tend to a cylindrical shape, rounded at the ends, and the cotyledons of the embryo within are white (perhaps in some varieties pinkish, but never purple) in colour.

Th. Cacao is nowhere known with certainty to occur in a truly indigenous state, but its centre of origin may have been in central America, with a natural range extending down through Colombia into western Venezuela. From western Venezuela it first became known and recognized as a commercial cacao, and it can still be found there in cultivation in a pure state, though on a diminishing scale. Introduced to Ceylon about 1834, it became famous as the 'Old Red Cacao' of that island, and it was also introduced to Java, where it built up a reputation as 'Java Criollo', and to Madagascar and Samoa. Its product has

always been accepted as the highest in quality of all commercial cacaos, but the tree itself has the general reputation of being delicate. Some truth in that reputation is indicated by the decline of Criollo cacaos from supplying the bulk of the world's requirements to the position of almost negligible contributors.

The other commercial species is *Th. leiocarpa* Bern. Its pods are oval, without distinct point, only shallowly furrowed, smooth, and commonly (perhaps always) yellow. The 'beans' tend to be lozenge-shaped and are distinctly flattened, and the cotyledons within are dark purple. This species has been found in an almost unquestionably indigenous condition in Dutch Guiana [2], and probably has a wide natural range in the Amazon and Orinoco basins. This, in an unhybridized condition, appears to be the commercial cacao of Brazil and of West Africa, and if that assumption is correct it accounts for some 82 per cent. of the present world crop. The quality of its product is low, but the tree is hardy and to that fact doubtless owes much, though not necessarily all, of its rapid rise in commercial importance.

Either by natural overlapping of ranges or by the agency of man, these two distinct species met long ago in eastern Venezuela, where by extensive and long-continued hybridization they lost their identities and gave rise to a tree population that is most conveniently described as the 'Trinitario mixture'. This is an astonishingly heterogeneous assemblage and defies accurate classification, though many writers have made confusion worse confounded by attempting to define 'varieties' within it. It contains individuals of the lowest possible quality alongside others only just short of the highest, but as a population it combines some of the quality inherent in *Th. Cacao* with some of the vigour inherent in *Th. leiocarpa*. Occasional individuals combine a very high degree of both, showing that the genes concerned are not necessarily antagonistic.

Over most of Venezuela, in Trinidad, in Ceylon, and in Java, introduced individuals from this mixture have supplanted the Criollo of earlier introduction by virtue of their greater hardiness and adaptability to conditions. In so doing they have become further hybridized with the older populations, so that although the cacaos of all these countries, together with those of Costa Rica and Grenada, must now be classed as Trinitario, the average quality of the mixture varies from country to country according to the extent of the Criollo contribution. Taking them all together, these hybrid cacaos at present represent about 15 per cent. of the world's crop, that is to say, the bulk of that proportion which is classified as 'fine' cacao, and commands a quality premium over the unhybridized *leiocarpa* product. The small remainder is made up of the remnants of pure Criollo and the 'Cacao Nacional' of Ecuador.

It is probably as much by chance as by merit that the commercial cacaos of to-day have practically all been derived from two sources, one in Brazil (*Th. leiocarpa*) and one in Venezuela (the Trinitario mixture). The cacaos of Peru, Ecuador, Colombia, and the central American countries from Nicaragua to Mexico are virtually unstudied botanically, but we have some evidence of genetically distinct material

in those countries. The 'Cacao Nacional' of Ecuador, for example, cannot be referred to either *Th. Cacao* or *Th. leiocarpa* with any confidence, and may prove on study to be a distinct species. It has at least very distinct varietal characteristics, and according to reports is much too uniform to be a mixture like Trinitario. In 'Nicaraguan Criollo' we have another high-quality cacao, which is probably related at least in part to *Th. pentagona* Bern. Only extensive collection in the remoter parts of the distributional range of *Theobroma* can now determine the number of genetically distinct types that may be at the disposal of growers and breeders of cacao in the future. At the present time an attempt is being made to find immunity or resistance to Witches' Broom Disease among some of the hitherto neglected local cacaos, and it is undoubtedly among them that we shall increasingly have to look for the means to make cacao easier and more profitable to grow.

For the present it is Trinitario cacao, especially as represented in Trinidad, that has received the most detailed botanical study, and of the two groups available for immediate improvement this is undoubtedly the more promising. The scope for improvement in *Th. leiocarpa* is limited by its narrow specific origin and consequently narrow range of variability. Possibilities of improvement by selection in West African cacao, for example, certainly exist, but sooner or later the limits of the pure species must be reached. On the quality side, in particular, they are likely to be reached rather quickly. At this point, if we are to judge from the evolution of other crops, the introduction of genes from another species will become desirable. In Trinitario cacao that introduction has been made already, and a widened range of variation is ready for selection of superior types adaptable to various sets of conditions.

Selection

A genetic survey carried out between 1930 and 1932 by Pound [3] first gave statistical precision to our knowledge of variation in Trinidad cacao. After determination of sampling constants, the mean values of pod dimensions for 950 trees, distributed in twelve blocks on good estates in various parts of the island, were found to be as given in Table 1. Individuals falling outside the given limits can be found, but they are rare, and the figures are fairly representative of the population.

TABLE 1. *Mean Values of Pod Measurements*

Dimension	*Lower limit*	*Upper limit*	*Mode*
Length	10·5 cm.	23·5 cm.	16·0 cm.
Diameter	6·1 cm.	10·6 cm.	8·0 cm.
Ratio (shape)	1·3	2·7	1·95
Shell thickness	0·8 cm.	2·4 cm.	1·4 cm.
No. beans	15	45	34·5
Pods to the pound	6	22	10·5
Weight of a single bean	1·1 gm.	5·6 gm.	3·2 gm.

On these results a selection programme was planned,[7] directed primarily at increasing yield, with quality neither neglected nor over-

stressed. In view of the wide variation in 'pod value', expressed by the finding that six pods from one tree may yield as much cacao as 22 from another, the obvious course was to make a first selection on pod value and to reselect on bearing qualities (i.e. number of pods per tree), with a correction for size of tree and area of ground occupied. In this way, by the end of 1935, 100 trees had been selected in different soils and locations, of various types and qualities, each actually yielding cacao at a rate of not less than one ton (cured beans) per acre. Details of procedure have been published by Pound [4] and by Cheesman and Pound [5].

In the course of the survey and the initial stages of selection, some interesting and highly important facts came to light. In the first place it appeared that pods containing a large amount of cacao usually have individually heavy beans. In other words the increased weight of cacao is due to increased size of beans rather than to increased number. Inasmuch as bean size is one component of quality, this finding indicated that the method of selection for yield involved to some extent an automatic selection for quality. Nevertheless it was still proposed to lower the yield-standard in the case of trees of outstanding quality, until it was further found that certain trees selected primarily for quality were passing easily the standard set for yield. In the end there was found scarcely any tendency among the selected trees for yield and quality to be antagonistic, and this is perhaps the most encouraging conclusion that has yet emerged from the work on selection.

Propagation

For the full exploitation of the results of selection in a tree crop the use of vegetative propagation may be regarded as essential, and for this reason studies of propagation methods have gone hand in hand with the selection programme. In this connexion, however, it is necessary to distinguish between the immediate objects of research and what have been called its 'long-range' aims. To view both in true perspective we have first to recognize that cacao has never yet been grown commercially by vegetative propagation except on an insignificant scale. It is true that such commercial experiments as have been made do not preclude the feasibility of the process, where reasonably intensive methods can be applied. On the other hand, the bulk of the world's cacao is grown by methods anything but intensive, and no immediate revolution in the industry is to be expected. Current discussions of the relative merits of buddings and clonal seed in rubber cultivation serve to show that the arguments are not all on one side when the choice has to be made between vegetative and seedling propagation in tropical crops.

Research in propagation is therefore not aimed at immediate change in planting methods, but there remain many reasons for its prosecution. Perhaps foremost is the necessity for uniform material to facilitate the crop physiologist and other investigators in planning and carrying out precise experiments. Then there is the advantage of clonal plantings for cheap control of pollination where selected seed of known parentage

is to be supplied. There is—by no means of least importance—the demand of the planter who can use intensive methods, and is prepared to do so, for the best planting-material available. There are dozens of questions in cacao-cultivation which can be answered only by horticultural experiments based on vegetative propagation.

The history of asexual propagation of cacao, which goes back forty years, has been summarized by Cheesman [6], together with an account of the horticultural problems involved. Recent work has been concentrated on propagation of selected trees on their own roots by the striking of cuttings, and a simple but efficient technique has been worked out [7]. Some of the first cuttings rooted are now four years old, and their growth has been quite satisfactory, both above ground and below.

A field experiment is now being planted to compare trees raised from cuttings with those propagated by budding the same clones on seedling-root-stocks. At the same time a dozen specially robust and heavy bearing trees have been selected and propagated for use as clonal stocks, and budding on these will be included in further tests. Such comparisons will serve the longer-range objects of research, and for more immediate purposes steps are being taken to compare cuttings with seedlings from the same trees.

The most immediate purpose of all in this clonal multiplication, however, is the testing and comparison of the selected trees, as it is on their clonal progenies that the soundness of the selection principles must be proved or disproved. Not only in yield, but in detailed behaviour, in habit, earliness, disease-resistance, and other respects the clones may be expected to differ significantly, and the differences may perhaps be turned to profit.

Factors Influencing Fruitfulness

Appreciable progress towards an understanding of the factors influencing yield in Trinitario cacao has been made by the discovery of widespread self-incompatibility in the tree population. First noticed by Pound [8], this phenomenon has been further studied by Voelcker [9], with the surprising result that a large number of the trees specially selected for their high yields are found to be almost sterile with their own pollen. Others, however, are apparently fully self-fertile.

On the one hand this discovery may help to explain the very wide fluctuations in yield from tree to tree, and the high proportion of poor bearers in the population. It may also be one cause of the disappointing results of selection in the past, when seedling progenies have been used, since it is apparently possible for a heavy bearer to set all its crop by cross-fertilization. On the other hand it opens up some new problems and throws fresh emphasis on some old ones. The agent of natural cross-pollination in the field has never yet been identified, and it is now clearly necessary to find out more about it. If it is an insect, fluctuating seasonally in abundance, it may have a great influence on the seasonal distribution of the crop, and this in its turn will be likely to affect final yield.

If vegetative propagation is not used commercially, the importance

of controlling the parentage of the seed supply on both sides is emphasized, and if vegetative propagation is to be used there are obvious dangers in planting monoclone blocks without exhaustive tests of compatibility.

For immediate purposes it is evidently advisable to concentrate on self-compatible clones, but as some self-incompatible trees are very high yielders of superior cacao, it does not seem advisable to drop them from selection lists without further trials. They may have horticultural characters making it profitable to interplant their clonal progenies with suitable pollinators. So far it has been found that pollen from a self-compatible tree sets fruit on a self-incompatible, but that pollen from another self-incompatible does not. Further investigation may reveal cross compatibilities among the self-incompatibles.

Not the least interesting point about self-incompatibility is that it does not seem to occur in West Africa. Whether it has been introduced into Trinitario by the Criollo parent, or whether it is a direct consequence of hybridity, absent in both the pure species, remains to be determined when we have fuller facilities for studying the Criollos.

Horticultural Outlook

From the horticultural point of view the significance of recent cacao research is that it has taken the first steps in substituting for a mixed population a number of selected lines or clones which can be studied intensively. The major issues between seedling lines and clones, between selfing and crossing of selections if seed is to be used, and between 'own roots' and foreign root-stocks if vegetative propagation is to be used, all remain to be worked out, along with many lesser problems. Analogy with other tree crops, having a longer history of research behind them, suggests not only that these steps are essential to progress, but that progress can scarcely fail to follow when they have been taken.

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THE CITRUS INDUSTRY IN PALESTINE

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Development.—The citrus industry of Palestine is vitally important to the economic life of the country as citrus is the only export commodity, either agricultural or industrial, of any considerable importance, comprising as it does more than 90 per cent. of the total exports. The capital invested, on an average basis of £75 for bringing a dunum[1] of citrus into bearing (5 years old), is conservatively placed at £22,250,000. This does not include the value of the land, which has either been in the same family for generations, or with the inflow of immigrants has been purchased at abnormal and often uneconomic prices.

The old groves were centred around the sandy areas of Jaffa and in a few other isolated places such as Acre, where the soil is a fairly retentive loam. After the British occupation in 1918 the Government took immediate steps to resuscitate the old groves, and since that time the development has been phenomenal. The groves now stretch almost continuously from south of Gaza to Zikhron Ya'aqov, a distance of 90 miles on the Mediterranean coastal plain, extending inland for a distance of 10 miles and to an elevation up to 675 feet. Beyond Acre there is a further considerable stretch of groves reaching almost to the Syrian border, as well as small ones. There are some comparatively small areas near the Lake of Tiberias and at the north end of the Jordan valley; also small groves at Jericho and in some protected mountain villages.

The old orange and lemon groves were largely owned by Arabs but during the last ten or twelve years, although they have made other large-scale plantings, those by Jews have been greater, and at the present time it is estimated that 60 per cent. of the groves are owned by Jews and 40 per cent. by Arabs. In 1922, 10,500 dunums were owned by Jews and 22,000 by Arabs and others, and in 1934 of 250,000 dunums, 149,000 were stated to be Jewish-owned.

The spread of citrus groves over a large area of country, much of which was undeveloped and connected only by sand or dirt tracks a few years ago, has necessitated considerable road and railway development. Today, main roads and railways connect the principal citrus areas with the ports, and, except for still further attention being needed to the feeder roads, communications in general may be regarded as excellent.

Citrus culture in Palestine includes the production of oranges, grapefruit, lemons, and tangerines. The most important of the oranges, particularly for export, is the Jaffa variety, locally known as Shammuti. It is typically oval in shape with rather thick and coarse skin, particularly on large fruit, practically seedless, and of sweet, good flavour. Its history can be traced back to the early seventeenth century [1], but there is some doubt whether it originated as a bud sport in an old Jaffa grove or was introduced from abroad. Less important varieties of oranges

[1] A dunum = 1099·5 sq. yds. = 0·227 acre.

grown on a comparatively small scale are the Beladi, or native variety, and the Fransawi, or French variety. These have, however, been largely top-worked with Shammuti, particularly in the old Acre groves, and they are thus less common than formerly. In the last few years Valencia oranges have been planted on a small scale.

Grape-fruit is almost entirely of the Marsh variety, with small areas of a seeded type resembling Duncan. The common lemon is known as Beladi and resembles the Lisbon; Eureka lemons are also grown. There are several varieties of tangerines, Clementine and Youssouf Effendi, a local variety, being most common.

Areas.—Oranges are estimated to comprise 90 per cent. of the total citrus groves, the remainder being mainly grape-fruit with some lemons and tangerines. Owing to low prices prevailing for several years, many grape-fruit groves are being top-worked to oranges or cut hard back to the stock, and the subsequent sprouts re-worked. An approximate statement of citrus planting which serves to illustrate the rapid development of the industry in the last ten years is given below:

TABLE 1. *Areas planted with Citrus in Palestine, 1922–1937/8*

Year	*Dunums*	*Year*	*Dunums*
1922	32,500	1931–2	15,000
1923–5	1,500	1932–3	35,000
1926–7	8,000	1933–4	43,500
1927–8	17,500	1934–5	46,500
1928–9	11,000	1935–6	28,000
1929–30	20,000	1936–7	20,000
1930–1	19,500	1937–8	1,500
			299,500 dunums

The Department of Agriculture and Fisheries is now undertaking, with the co-operation of the Commissioner for Lands and Surveys, a detailed survey of all groves to obtain accurate records of areas planted, ages and kinds of trees, stocks upon which they are budded, planting distances, &c. More than two-thirds of the total area has already been surveyed. This information is particularly needed for crop estimation, which under present conditions can only be done in a somewhat haphazard manner.

Exports.—Palestine oranges have long been known in Europe. Tolkowsky [1] has collected evidence of various writers as to their presence in these, and in distant, regions in 1852 and 1857, and quotes from a report of Guerin in 1863 that 'large cargoes of Jaffa oranges are sent each year to different ports of Asia and Europe'.

In the year 1885 exports totalled 106,000 'boxes' and the fairly complete records since that date show that annual shipments varied from 200,000 to 550,000 boxes between then and 1906, followed by a steady annual increase up to 1,609,000 boxes in 1913. Shipments ceased during the War but thereafter progressed year by year with little set-back, as Table 2 shows.

Yields.—The average yield of a dunum of full-bearing orange trees is generally accepted as 100 boxes, of which 80 are suitable for export, and

TABLE 2. *Exports of Citrus Fruits from Palestine, 1919/20–1937/8*

Year	*Boxes*[1]	*Year*	*Boxes*[1]
1919–20	647,063	1929–30	2,897,686
1920–1	830,959	1930–1	2,488,937
1921–2	1,234,251	1931–2	3,734,556
1922–3	1,365,543	1932–3	4,498,241
1923–4	1,589,331	1933–4	5,525,334
1924–5	2,146,457	1934–5	7,330,846
1925–6	1,518,731	1935–6	5,897,310
1926–7	2,668,291	1936–7	10,786,365
1927–8	2,220,443	1937–8	11,200,000[2]
1928–9	1,802,547		

for grape-fruit 120 boxes, of which 100 are exportable. In future the estimate for the yield of exportable grape-fruit per dunum will probably be nearer that of oranges, owing to the tendency to restrict the export of certain of the large and small sizes. Appreciable yields do not usually occur until the trees are 5 years old, and full-bearing is not reached until 9 or 10 years. All groves of more than 7 years of age are subject to a land tax of ten shillings per dunum.

Future crops.—Reference to Table 1 will show that of the total area of 299,500 dunums planted up to December, 1937, 174,500 were less than 7 years old. Average yields calculated at 80 boxes per dunum for all orange and grape-fruit groves over 7 years of age[3] give an approximate estimated production of exportable fruit for the next few years as shown in Table 3, from which it will be seen that in 5 years' time present exports will be doubled.

TABLE 3. *Estimated Future Exports of Oranges and Grape-fruit*

Year	*Estimated exports (boxes)*
1938–9	12,800,000
1939–40	16,240,000
1940–1	20,000,000
1941–2	22,240,000

By-products.—The disposal of the large quantities of 'cull' fruit, mainly of sizes too big for export, presents considerable difficulties. Young trees, of which there is a high proportion, yield larger oranges than do older trees, and this is particularly true of the Jaffa orange, which is typically rather a large fruit. Considerable attention is being given to utilizing them in the development of a by-products industry,

[1] According to the latest regulations (Aug. 30, 1937), boxes may vary within the following dimensions: oranges 68–74 × 34–37 × 27–30 cm.; grape-fruit 66–74 × 33–37 × 29–30 cm. There is also provision for testing three other sizes in an effort to standardize. The number of oranges in a 'box' may range from 120 up to 360, and the number of grape-fruit from 80 to 112, in accordance with the regulations of Jan. 22, 1938.

[2] Total exports shortly before the close of the season; there are still a few small shipments to be made.

[3] As groves of 7 years of age are not in full bearing, an average yield of 80 boxes is approximated by omitting to take into account the small crop from the trees from 4 to 7 years of age.

and several factories exist for the preparation of citrus juices, syrups, essential oils, marmalade, and canned goods. There is quite a large local trade in juice, syrups, and canned goods, but exports at present are comparatively small. The Daniel Sieff Institute continues to conduct research for the purpose of obtaining a concentrated juice by a process of partial freezing and centrifuging, and also into methods for converting the residue into economic products.

Climate.—Palestine is typically an arid country; the annual rainfall of the citrus area on the coastal belt ranges from 12 in. in Gaza to 24 in. in Acre, and falls entirely within the period, end of October to early April. The greater part falls during the months December to February, light showers only occurring in late autumn and early spring. During the winter it is not unusual for strong and cold winds and sporadic hail-storms to do severe damage to the trees and fruit; frost rarely does any real harm to them. During the summer months temperatures are very high, the monthly mean ranging from 81° to 92° F. In spring, hot dry winds carrying sand, and known as 'Khamsin', often occur and not infrequently cause severe damage to the trees, resulting in a heavy 'June drop' of the young fruit. The smallness of the 1935–6 crop, as compared with that of the previous year (see Table 2), was due to Khamsin occurring in May, 1935. Khamsin in early autumn may also cause damage, resulting in shedding of leaves and fruit.

Irrigation.—Apart from the natural requirements of soil and climate, water is the most important factor in the development of a citrus grove in Palestine. A surface-supply is only to be found in very few areas and even in these it is limited and has to be supplemented. Fortunately there is a plentiful underground supply in the areas best suited for citrus. Wells or bores vary from 10 to 100 metres in depth, but most groves obtain their supplies between 20 and 30 m.

Quality of water is an important factor, and in particular its salinity. Reifenberg [2] finds that the springs and sub-soil waters of Palestine are richer in soluble salts than European waters, and suggests that the limit for citrus is around 350 mg. of chlorine per litre of water, subject to variation on account of other factors, presence of other salts, variety of citrus, and the nature of the soil. Waters excessively saline lead to chlorosis, loss of crop, die-back of branches, and subsequent death.

At the Horticultural Station at Farwana, in the Jordan Valley, marked differences were observed on small experimental plots of citrus grown on land watered by three springs of varying degrees of salinity, viz. 88–106, 213–36 and 380–90 parts of chlorine per million of water. The plot watered by the spring containing the highest percentage of salt produced yellowish, stunted trees, as compared with those supplied with water of lower salinity. Rough-lemon stocks showed better growth and development under adverse conditions than sour orange or pomelo. These results relate only to small-scale tests, and further investigations are needed to ascertain the maximum amount of salt which different varieties of citrus will tolerate under a variety of soil conditions; experiments are being continued.

Irrigation practices vary considerably as to the amount of water used,

the period between applications, and the method adopted. The period may vary from 10 to 45 days with 20–6 irrigations during the season. The amount of water applied usually varies with the period and the number of trees. Many growers accept 500 cubic metres per dunum per annum, as an average figure. Duty of water investigations are being conducted by the Department of Development in Palestine with the idea of solving some of these problems.

Shepherd [3] shows that an unnecessarily large amount of water is generally used in citrus groves in Palestine, and that a grove 3 years old may be maintained in excellent condition and give high yields with water applied at 44 days intervals, 360 cu.m. being applied in three irrigations.

Groves are usually watered by the 'basin' system, a shallow depression being formed around each tree, or between the trees, into which the water is guided through soil channels. Some growers in the Acre area continue to use the harmful and wasteful process of 'flooding' the land, a method which does not provide for an equal and economical distribution. The furrow system, one in which the water is conducted by soil channels between the rows, is being tried in some young groves. Its advantages for citrus in keeping the collars of the trees free from immediate contact with the water, and in causing a thorough soaking of the outer areas of the rooting system, need no emphasis.

Drainage.—Much of the area under citrus is on light, free-draining land, but in other parts where the soil is retentive or the grove low-lying, water is apt to accumulate during winter storms, and drainage is necessary. This important provision is, however, often neglected, with the consequence that the fruit from these particular groves is highly susceptible to wastage diseases.

Wind-breaks.—There is little natural protection from wind for citrus groves in Palestine, and it is very desirable, if not a necessity, to establish wind-breaks in all groves. The ill effects of exposure to wind are obvious on the condition of trees in unprotected groves, and investigations [4] have already revealed their influence on the yield, soundness, and grade of the fruit. Trees commonly used as permanent wind-breaks in Palestine are *Cupressus pyramidalis*, *C. horizontalis*, *Eucalyptus* spp., and *Casuarina*; *Cupressus macrocarpa*, *C. arizonica*, and Tamarisk are used to a less extent, the latter being particularly suited to groves located near the sea-shore. *Cupressus* are usually planted at distances varying from 1–3 m. in one or two rows, and lightly topped about every two years to make them grow more bushy. Permanent hedges are commonly formed of *Opuntia* and *Acacia farnesiana*, both of which form impenetrable thickets; sour orange, castor oil, *Arundo Donax* and *Aberia caffra* are also used. Trials of a number of plants likely to prove suitable as temporary wind-breaks are being undertaken at the Horticultural Stations, and of these sunn hemp (*Crotalaria juncea*), *Sesbania aegyptiaca*, and selected strains of pigeon pea (*Cajanus indica*) introduced from Trinidad, appear to be particularly promising for protecting young groves in summer. Sunn hemp, an annual, grows to a height of 2 m. within 2 months; *Sesbania* and *Cajanus*, both perennials, do not entirely resist the cold of winter, but the bushes recover again with the coming of spring.

Stocks.—The normal procedure for establishing a grove is to plant the root-stocks *in situ*, where they are grown for two years before being budded. The stock commonly used was sweet lime (*Citrus limetta*), and it is estimated that 90 per cent. of the Jaffa orange trees are budded on to it. Grape-fruit and Valencias are nearly all budded on sour orange. Sweet-lime stocks are generally used for the light soils and sour-orange stocks for the heavier. Whilst there are certain disadvantages attached to the use of each, both are valuable root-stocks for particular soil conditions. There are certain disadvantageous reactions with these two types of stocks for the principal varieties of citrus and, so far as present observations go, the Jaffa orange on sour stock is late in coming into bearing, has a tendency to alternate light cropping, and is more susceptible to damage by Khamsin than when budded on sweet lime, effects which are not usually produced in Valencias or grape-fruit on sour stock. The sweet lime is more susceptible to gummosis than is sour orange, and when budded at too early an age is subject to Xyloporosis [5]. Experiments with other types of stocks are being made in the Agricultural School at Mikveh Israel, and the subject is in general receiving much attention by the Horticultural Service of the Department of Agriculture, and by the Jewish Agency Agricultural Research Station, at Rehovoth.

Variation in the Jaffa orange.—The Jaffa orange is reported [6] to be as susceptible to variation as the Washington Navel and Valencia oranges, and many different forms are known. To this variation is attributed the occurrence of inferior types, which in some groves are stated to range from 5 to 18 per cent. In recent years more attention has been paid to the selection of bud-wood from trees known to be of good quality and yield, and in many groves it is the practice to uproot or top-work trees of poor type as they are noticed, and replace them with the true Jaffa.

Spacing.—Perhaps the main difference in citrus culture in Palestine from that prevailing elsewhere is the close spacing of the trees; in very old groves there are as many as 100 trees per dunum planted at irregular distances. Under such conditions it is impossible to carry out mechanical tillage, and to move about the grove for the purposes of transporting the crop, manuring, &c. it is necessary to crouch under the trees; the difficulties encountered when gathering the crop may well be imagined. There are, however, some advantages to be gained by close planting; the yield per dunum is much heavier for the first 15 or 20 years, the fruit is smaller and less coarse, and the trees afford each other protection from wind, a particular advantage in those groves which have no wind-breaks.

In the younger groves the trees are usually more widely spaced, being planted at distances of 4×4 and 4×5 m., but even this is much closer than the generally accepted rule in other countries. In Palestine there is now a tendency to revert to closer spacing with oranges, and some young groves are being interplanted with one tree between each four so as to form a quincunx system of spacing. Grape-fruit is usually planted at distances of 5×5 or 6×4 m. At the Government Citrus Demonstration Station at Sarafand, experiments have been in progress for the last three years with Jaffa oranges budded on sweet-lime stock, planted at distances of 4×4, 4×6, and 6×6 m. Similar trials with Jaffa

orange on sour stock are also being made. At the Jericho Horticultural Station spacing trials have been in progress for the past ten years, and under the exceedingly high temperature and hot winds prevailing in the Jordan Valley during the summer months, present indications are that 4×4 and 5×5 m. are more suitable spacings than 7×7 m., and the trees planted at 3×3 m. are much too crowded.

Tillage.—In the main citrus area it is somewhat unusual to find groves which are not regularly and systematically tilled, and throughout the summer months they are practically free of weed-growth. Much of the tillage, particularly in the old groves, has, owing to close planting, to be done by hand, and this is usually carried out simultaneously with the preparation of the land for irrigation and manuring. The younger groves are usually tilled with primitive ploughs, or with disk and modern ploughs, either horse- or tractor-drawn. On undulating land it is necessary to form the soil into contour-ridges before winter begins in order to prevent soil erosion.

Planting.—It is quite common to find trees in the groves much too deeply planted, and this is one cause of the losses from certain root and collar diseases, such as gummosis.

Tree-formation.—Orange trees in the new plantings are usually allowed to branch at about 60 cm. from ground-level, and grape-fruit and lemons at about 80 cm. In many old orange groves the stock was often allowed to branch before budding and the buds inserted in the branches; in such groves it is not uncommon for the junction of the branches with the main stem to be below ground-level.

Pruning.—Pruning in the early years is mainly confined to shaping the trees and the removal of 'water-shoots'. When a complete canopy over the land is formed, dead wood begins to appear, particularly in the lower branches, and closely spaced trees therefore need more regular attention for its removal than do those which are wider apart.

Sanitation.—Grove sanitation is often neglected, particularly after storms, when much fruit is either torn from the trees or damaged. This fruit, if allowed to remain in the groves, as was the practice until recently, soon becomes heavily infested with *Penicillium* and *Diplodia*, and under normal conditions of packing causes a serious risk of infection to the packed fruit. At the beginning of this season the Fruit Inspection Service was strengthened by the appointment of ten itinerant inspectors with power to enforce cleanliness in groves and all places where packing is conducted, and to suspend packing where the conditions of the Citrus Fruit Export Regulations are not complied with. This marks a considerable step forward in the efforts to reduce wastage in fruit exports; and as a further effort a programme of research was arranged in 1937–8, financed by a tax of $\frac{1}{2}$ mil on each box of citrus exported.

Manuring.—Palestine, like most other citrus-growing countries, has no 'golden rule' for manuring and fertilizing. Seasonal applications largely depend on the individual ideas of the grower, the money he can afford to spend, and the manures and fertilizers available. Sheep and goat droppings are the common form of organic manure; but with the rapid extension of groves the supply is now quite inadequate. Manufactured

manures are coming more into general use, and some attention is being paid—so far with little result—to producing supplies by the conversion of town refuse. In recent years, owing to the need of receiving payment in kind from certain countries, some manures and fertilizers have been obtained in payment for the citrus shipped to them; the suitability of some of these has yet to be proved. The price of local supplies of goat and sheep manure has risen with the demand, and now costs about £P. 1 per ton delivered at the grove. As purchased from the fellaheen or Bedu it is often of very poor quality, being adulterated with dirt, gravel, straw, &c. Applications vary from 35 to 150 lb. per tree, an average dressing being about 75 lb.

Routine fertilization of citrus at the Horticultural Stations consists of applications of sulphate of ammonia or nitrate of soda (the latter only on light soils) before the last rains in March, with a further application either of these or of nitro-chalk in May or June with the idea of reducing crop loss from 'June drop'. A similar dressing is applied towards the end of the summer, and goat, sheep or stable manure, superphosphate, and sulphate of potash in September or October. Soils in which the percentage of lime is below 7 are dressed with not less than 60 kg. of quicklime (slaked before application) in June or July. An example of the annual treatment of old groves, based on these general principles and as adopted at the Horticultural Stations and some private groves, is shown below:

Time of application		*Kg. per tree*
Mid-March	Sulphate of ammonia or nitrate of soda	0·4
May	Sulphate of ammonia or nitro-chalk or nitrate of soda	0·3
July-Aug.	Sulphate of ammonia or nitro-chalk or nitrate of soda	0·3
Sept.–Oct.	Goat, sheep or stable manure	30·0
	Double superphosphate (40 per cent.)	0·35
	Sulphate of potash	0·25

Some of the local research institutions are investigating manurial and fertilizing problems. Green manures are not in general use and cannot be grown where the trees are crowded. In the horticultural stations and in some of the younger groves, field beans (*Vicia faba*) are used for the heavier soils, and lupins (*Lupinus* sp.) for the lighter. Sown with the first rains of autumn, they make good growth ready for ploughing under during their blossoming stage in January. In the Tiberias sub-district, cow peas and *Crotalaria mollissima* are used as spring and summer green-dressings, being sown in February.

Pests and diseases.—The presence of pests and diseases calls for routine treatment in most groves, such pests as Mussel scale, red scale, and black scale are controlled either by spraying or fumigating, and Mediterranean fruit fly by trapping bottles, poison baits, or poison-bait sprays. Root and collar diseases are treated by surgical and other means.

Handling the crop.—The citrus season is one of great activity in Palestine, providing as it does employment for large numbers of persons in many stations of life.

Methods of preparing the crop for market are still primitive as compared with those of most other citrus-growing countries, but considerable

progress has been made of late and the quality of exports has improved. There are very few central packing-houses, most of the fruit being packed in or adjacent to small sheds, or yards to be found in nearly every grove. The fruit is clipped from the tree, usually with ordinary sécateur, the stem being cut close to the fruit, with a second cut after it is severed from the tree; spoon-bladed, blunt-nosed clippers are rarely used. It is then placed in sack-lined baskets and carried on the backs of labourers to the place of packing, where piles one or two feet deep are made, and allowed to wilt for periods varying from 1 to several days; or it may be put in field-boxes and allowed to wilt in them until ready for packing.

Except in the central packing-houses, the fruit is not sized mechanically, and in other places it is carried on simultaneously with the grading. The degree of accuracy attained by expert sorters in sizing 'by eye' is really remarkable. Wrapping and packing are not done by the same person as one complete operation—the usual method in modern packing-houses—but the local procedure is for the fruit to be wrapped and placed ready for the packer, who sits on the ground and packs with the box inclined towards him. The finished pack is a flat one, and strengthened on the two ends and centre with wooden hoops. There is no one standard box, although the maximum and minimum sizes used for the different 'counts' are controlled by law. The use of a standard box for the Jaffa orange has received much attention in recent years, but owing to the oval shape of the fruit it does not appear to be so readily adaptable for the purpose as the rounder types of oranges. There is, however, much less variation in the sizes of the boxes than formerly, and it is probably only a matter of time before complete standardization is effected (cf. footnote on p. 227).

Fruit inspection.—Transport from the grove to the port or railway station is undertaken by lorry, cart, or camel. On arrival at the port the fruit is received by Government fruit inspectors, who examine the consignment note accompanying it, and select at random up to 5 per cent. of the cases for examination to see whether they conform to the Citrus Fruit Export Regulations. If the boxes contain an average of more than 2 per cent. defects, a total of 10 per cent. of the cases has to be examined, and if the percentage of defects is maintained the entire consignment is not allowed to be exported; instructions are given for repacking under supervision of Government inspectors, or disposal in other ways according to the reasons for rejection.

The general standard of citrus exports has much improved since 1928, the year when the Government Fruit Inspection Service first began to operate under the Citrus Fruit Export Ordinance and Regulations of 1927. Each year since that date the regulations have been revised and strengthened [7] and the fruit-inspection staff increased in keeping with growing exports and higher standards. All will admit that there is still much to be done despite the steady improvement which is taking place.

The Citrus Fruit Export Regulations now provide for control of the opening date of the export season, for maturity tests, sizes of boxes, condition of the fruit for export, methods of packing, marking of the

boxes, registration of exporters, suspension of picking of fruit in water-logged groves, sanitation of groves, condition of packing places, &c.

Grape-fruit is not allowed to be exported before the first of October, and oranges prior to November 20, unless they have passed a test for maturity standard. The season continues until March or April, but as the greater part of the orange crop is marketed in the United Kingdom, it is usual to export most of it so as to arrive in England between the period December 1 and March 31, during which a reduced duty operates.

Port facilities.—The main ports of Palestine are now well equipped for the citrus trade. Large airy transit sheds are available for storing fruit awaiting shipment. At the Haifa port the steamers can tie up alongside the quay, and loading is done by modern methods. At Jaffa and Tel-Aviv the steamers have to lie off at some distance from the shore and be loaded from lighters which load in sheltered harbours.

Ocean transport.—The fruit is carried almost entirely as unrefrigerated cargo, and proper provision is not always made for ventilation. Steamship services are, however, gradually improving and many of the ships are now fitted with a circulating-air system.

Marketing.—Marketing is a major problem, hampered as it is in most countries by high duties, currency restrictions, and quotas. Unless some means are found for removing at least some of these drawbacks the future of the industry is not particularly bright.

Every effort is being made to increase the consumption of citrus fruit by extensive advertising abroad and in Palestine. Exporters contribute 3 mils (approximately three farthings) per box on all exports, and a sum of £40,000 is being spent in 1937–8 on cinema, radio, press, and general propaganda in twenty-one countries.

The many problems connected with the production, transport, and marketing of the crop are under constant examination by several committees working under Government aegis for the good of the citrus industry.

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A PRELIMINARY STUDY OF THE EFFECTS OF MANURIAL TREATMENT, AND OF AGE, ON THE CAROTENE-CONTENT OF GRASS

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Introduction.—The annual value of the grass crop in England and Wales cannot easily be computed, but when it is stated [1] that of 24,863,114 acres of enclosed agricultural land 17,844,417 acres are in temporary or permanent pasture, and that 5,433,477 acres of rough grazings are predominantly grass, there should be no necessity to stress the supreme importance of this crop as a food for live stock.

During recent years considerable attention has been given to artificial drying as a means of preserving young grass for use in winter feeding. It is not improbable that if grass-drying eventually takes a permanent place in agricultural practice, its primary object will be the home-production of cheap protein. At present, however, the carotene-content of the product is regarded as its chief asset, and must inevitably remain of considerable importance in view of the known effect of dried grass on the colour of winter milk, and of its value as a source of vitamin A to all classes of live stock. Grass, whether fresh or artificially dried, is almost the only source of vitamin A available to farm live stock, and it is obviously desirable that the feeder should be informed as to its carotene-content, and the means whereby he may control it. The two factors most likely to affect carotene-content are manurial treatment and age at grazing or cutting, both of which are controllable. The species constituting the sward are probably not without influence, particularly in the later stages of growth, but when grass is young—and it should be young when grazed or cut for drying—this factor may be less important; in any event it is less susceptible of control.

Such information as is available relates almost entirely to crops other than grass, and is derived from the results of experiments in pots. The authors have been unable to find any reference to the effect of fertilizers on carotene-content prior to 1929, when Guthrie [2], working with soya-bean plants, showed that an insufficient supply of nitrate nitrogen adversely affected the amounts of both carotenoids and chlorophyll present. More recently Virtanen and co-workers [3] have shown that the production of carotene is directly related to the facility with which the plant can utilize a given nitrogen supply, and that nitrates are superior to ammonium salts. Furthermore, they stated that a maximum carotene-content was reached when plants were grown at optimum pH which, for wheat and peas, was assumed to be 6·5. These two plants were grown in quartz sand, and watered daily with a nutrient solution supplying a constant amount of nitrogen as ammonium sulphate, potassium nitrate, or ammonium nitrate. Each source of nitrogen was applied to a series of five cultures, the acidities of which were adjusted by means of

sulphuric acid to give pH values of 4·0, 5·0, 6·0, 6·5, and 7·0, respectively. Virtanen's results from wheat, cut in full flower eight weeks after sowing, are shown below.

These figures clearly indicate that maximum carotene-production has occurred at pH 6·5, but the evidence for the superiority of nitrate over ammoniacal nitrogen does not appear to be so complete. It will be noted that the use of ammonium nitrate has resulted in a substantially higher carotene-content at optimum pH than the application of a salt (potassium nitrate) containing only nitrate nitrogen. Haber and Swanson [4] state that Dutcher, in some unpublished work, observed that spinach

Source of nitrogen	*pH*	*Carotene mg. per gm. dry matter*
Ammonium sulphate	7·0	0·0669
	6·5	0·0826
	6·0	0·0743
	5·0	0·0729
	4·0	0·0514
Potassium nitrate	7·0	0·0937
	6·5	0·1128
	6·0	0·1081
	5·0	0·0601
	4·0	0·0376
Ammonium nitrate	7·0	0·0896
	6·5	0·1814
	6·0	0·0913
	5·0	0·0890
	4·0	0·0398

grown in soil containing insufficient manganese manufactured less carotene than when grown in the presence of adequate amounts. The effectiveness of nitrogen was confirmed by Ijdo [5], who also found that the application of potassium salts reacted adversely on carotene-content, an observation that may explain the superiority of ammonium nitrate to the potassium salt evident in Virtanen's work. According to Ijdo, calcium and magnesium salts, and phosphates, have little effect.

Even less information is available concerning the effects of age at cutting. Virtanen [3] found that with wheat and peas, active carotene-formation occurred in the young plant, and reached a maximum at the time of flowering; thereafter a very marked decline was observed. He states that a similar decline occurs in cultivated grasses and renders an early haymaking and the taking of several crops each year much to be desired. Confirmatory evidence for such a post-flowering decline in grasses is not given. The only other reference to age-effect which has been found relates to the work of Deleano and Dick [6] on the carotene-content of the foliage of *Salix fragilis*, and has little bearing on the present investigation.

Experimental

A series of plots was laid down in the spring of 1937 on the Roundabouts field at Cockle Park. This field had been used for some years

prior to 1933 for an investigation into the Hohenheim system of intensive grassland management [7] which, it may be noted, had produced marked changes in the botanical character of the herbage. The nature of these changes has been discussed in some detail by Thomas and Boyns [8], and it need only be said here that approximately 70 per cent. of the ground is now covered by *Holcus lanatus*. The soil is typical of large areas of Northumberland, being a heavy loam derived from and overlying the Boulder Clay; it has the following analysis:

	Per cent. of air-dry sample		*Per cent. of air-dry sample*
Coarse sand	15·20	P_2O_5, HCl-soluble	0·095
Fine sand	32·80	K_2O, HCl-soluble	0·177
Silt	12·28	P_2O_5, available	0·012
Clay	24·47	K_2O, available	0·012
Moisture	2·08		
Carbonates	nil		
Loss by solution	1·40		
Difference	11·77	pH	6·34
	100·00		

An area of 43½ yds. by 11 yds. was divided into 12 rectangular plots, each 9 yds. by 3 yds., there being a margin of 1 yd. all round, and paths ½ yd. wide between plots. The whole area was surrounded by a post-and-rail fence netted to exclude rabbits.

Plots 1 to 8 were used for investigating the effects of manurial treatment, all being cut monthly; the last 4 remained untreated and were cut at intervals of from 1 to 4 weeks. The treatments used are summarized below:

TABLE 1. *Manurial and Cutting Treatments*

Plot nos.	*Treatment*
1 and 8	No manure
2 and 7	112 lb. per acre sulphate of ammonia applied one month prior to each cut
3 and 6	50 lb. per acre commercial sulphate of iron applied one month prior to each cut
4 and 5	3 tons per acre carbonate of lime applied one month prior to first cut
9	Cut weekly
10	Cut fortnightly
11	Cut at intervals of 3 weeks
12	Cut monthly

As the dressings of sulphate of ammonia and sulphate of iron were too small to admit of sufficiently uniform distribution, each was mixed with 14 lb. of silver sand prior to application. Plots 1 to 8 were arranged so as to compensate for any fertility drift in the direction of the major axis of the experimental area. All plots were cleared and mown closely on May 13, the carbonate of lime and the initial dressings of sulphate of ammonia and sulphate of iron being applied on that day. Thereafter the plots were cut with a 12-inch garden mower at the intervals indicated above. The total yield of each plot was weighed on the field immediately

after cutting, a sample for analytical purposes being placed in an air-tight tin.

On arrival in the laboratory a sub-sample of approximately 20 gm. was drawn from each tin, cut finely with scissors, and used for the determination of carotene. The remainder of each sample was weighed and dried for 24 hrs. in an electric oven at 100° C. Carotene was determined on the fresh grass by the method of Ferguson and Bishop [9]. The crude-protein, ash- and silica-contents of the dried samples were found by the usual analytical methods. Corrections for soil contamination were made by means of Woodman's formula [10], which assumes a silica-content of 1·72 per cent. for clean pasture grass. For the application of this formula 3 samples of surface soil were obtained from (*a*) unmanured plots (nos. 1, 8, 9, 10, 11, 12), (*b*) plots receiving sulphate of ammonia or sulphate of iron (nos. 2, 3, 6, 7) and (*c*) plots receiving carbonate of lime (nos. 4, 5). Soil ash and silica were determined on these samples by the analytical methods applied to the grass.

The character of the weather during the experimental period is indicated by the data shown in the following table:

TABLE 2. *Meterological Data*

Month	*Rainfall (inches)*	*Average rainfall for 15 yrs. 1919–33 (inches)*	*Sunshine (hours)*	*Average sunshine for 15 yrs. 1919–33 (hours)*	*Temperature*		
					Mean grass min. (°F.)	*Mean screen max.* (°F.)	*Mean screen min.* (°F.)
May . .	3·27	2·27	148	167	40·0	57·8	41·5
June . .	1·53	1·72	157	185	45·0	62·4	45·3
July . .	1·83	2·95	132	156	47·2	65·6	51·6
August . .	2·58	3·20	134	125	47·6	66·5	50·6
September .	1·88	2·30	119	129	41·7	60·8	46·0
October . .	3·01	2·72	65	105	39·0	54·6	43·2

Briefly, it may be stated that the weather was dull, dry, and rather warm. The amount of sunshine was below average in all months except August, and rainfall in all months but May.

Results

Effects of manurial treatment.—The carotene- and crude-protein contents of all samples, and the yields of dry matter, carotene and crude protein, together with their means, are given in Table 3.

The mean seasonal carotene-contents shown in Table 3 indicate that sulphate of ammonia has produced an increase of more than 30 per cent. over the control, and of more than 20 per cent. over any other treatment applied. The significance of these increases is obvious from the consistently greater effectiveness of sulphate of ammonia on all cutting occasions. Sulphate of iron, used at a somewhat lower rate than is common in greenkeeping practice, but applied monthly, may have produced a slight rise in the carotene-content of the last cut of the season, but otherwise proved completely ineffective. There is some evidence that

carbonate of lime—applied in amount more than sufficient to satisfy the lime-requirement of the soil—has increased carotene-content, but the effect, if real, has been comparatively slight.

TABLE 3. *Yields and Contents of Carotene and Crude Protein*

Date of cutting	**June 10*	*July 8*	*Aug. 5*	*Sept. 2*	*Sept. 30*	*Mean*
DRY MATTER (lb. per acre)						
No manure	847	406	536	457	260	502
Sulphate of ammonia	1,032	546	795	707	490	714
Sulphate of iron	706	429	458	395	203	438
Carbonate of lime	550	516	475	429	290	452
Mean	784	475	566	497	311	
CAROTENE (mg. per cent. of dry matter)						
No manure	29·1	30·6	38·5	57·5	61·2	43·4
Sulphate of ammonia	38·2	51·4	53·2	71·2	76·2	58·0
Sulphate of iron	26·1	21·0	30·5	61·6	68·0	41·4
Carbonate of lime	34·8	36·0	53·0	58·4	58·9	48·2
Mean	32·1	34·8	43·8	62·2	66·1	
CAROTENE (lb. per acre)						
No manure	0·247	0·124	0·207	0·263	0·159	0·200
Sulphate of ammonia	0·394	0·281	0·423	0·504	0·374	0·395
Sulphate of iron	0·184	0·090	0·140	0·244	0·138	0·159
Carbonate of lime	0·192	0·186	0·252	0·251	0·171	0·210
Mean	0·254	0·170	0·255	0·315	0·210	
CRUDE PROTEIN (per cent. of dry matter)						
No manure	19·86	18·17	14·81	20·13	24·12	19·42
Sulphate of ammonia	21·06	20·52	19·87	21·83	25·45	21·75
Sulphate of iron	19·11	18·24	20·13	20·11	25·22	20·56
Carbonate of lime	19·66	16·71	17·92	21·03	21·47	19·36
Mean	19·92	18·41	18·18	20·78	24·07	
CRUDE PROTEIN (lb. per acre)						
No manure	168	74	79	92	63	95
Sulphate of ammonia	217	112	158	154	125	153
Sulphate of iron	135	78	92	80	51	87
Carbonate of lime	108	86	85	90	62	86
Mean	157	88	104	104	75	

* The carotene-xanthophyll ratio was not determined in any samples cut on this date, carotene-content being calculated from total carotenoids by the use of a mean ratio for each treatment, obtained from the remaining cuts.

The results obtained from sulphate of ammonia were not unexpected, and bear out the findings of Guthrie and other workers already referred to, whose investigations were confined to pot cultures. The mechanism of this nitrogen effect is uncertain, but there appears to be sufficient evidence of a direct relationship between nitrogen-supply and chloro-

phyll-production [2, 11, 12, 13]. If, as is stated by Willstätter and Stoll [14], and by Schertz [13], the carotene-content of plants fluctuates with the chlorophyll, the effectiveness of nitrogen compounds in promoting carotene-production is explicable. It is commonly accepted that a sufficiency of iron is necessary for the production of chlorophyll, and that chlorosis results from an inadequate supply of this element. Oserkowsky [15] has established a correlation between the chlorophyll-content of leaves and what he terms 'active iron'. The ability of sulphate of iron to impart a beautiful dark-green colour to grass has been referred to by Dawson and Evans [16], and is well known. Such an effect was clearly noticeable in the course of the present work, plots having received sulphate of iron being identifiable at a considerable distance. It was expected that a marked increase in carotene-content would accompany increased chlorophyll-production. From the results obtained it is evident that this has not occurred. As with sulphate of iron, an increase in carotene-content from the application of carbonate of lime might reasonably have been expected. Thomas and Elliot [17] have shown that on pasture soils of the same type, reaction exerts a predominant influence on nitrification, and that a limed plot has a nitrifying capacity which is markedly superior to that of adjacent unlimed land. It should be noted, however, that in the present investigation lime was not applied until 4 weeks before the first cut was obtained, and that its maximum effect was not likely to be exerted before the conclusion of the experiment. As already indicated, the results obtained do not justify any confident conclusion, and further investigation is desirable.

A study of the seasonal variation in carotene-content shown by samples from all treatments, and by the means for treatments, reveals that there has been a very marked and consistent rise throughout the cutting period. Under three treatments (including the control) the percentage of carotene in the grass rose, from first to last, by 100 per cent. or more. Carbonate of lime produced a rise of nearly 70 per cent. Apart from some work carried out in Kansas by Atkeson, Petersen and Aldous [18], in the course of which samples of different species were taken in May, July, and November, no information on seasonal variation appears to be available. These workers found that carotene was high in spring, was much lowered in July, and in more than 60 per cent. of the grasses examined, rose again in late autumn. Unfortunately the present experiment has provided no information concerning the carotene-content of grass before June, but the consistent and undoubtedly significant rise which has occurred during summer and autumn is of interest, and may be of much importance in relation to the production of grass for drying. It is well known that autumn grass, when considered on a basis of crude-protein content, is often exceedingly rich, and may be equal in this respect to grass produced during the flush period in spring. There is evidence, however, that the biological value of the autumn protein is inferior to that of protein produced in spring, and although an outstandingly high carotene-content can in no way make good a deficiency of this character, it may constitute a valuable compensatory factor.

In considering the yields (in lb. per acre) of carotene produced by the

various treatments, it is necessary to examine the yields of dry matter in conjunction with the carotene-contents discussed above. Sulphate of ammonia has produced a markedly and undoubtedly significantly higher yield of dry matter on all cutting occasions than any other treatment. This was to be expected and calls for no comment. The mean yield from the plots receiving carbonate of lime was well below that from the controls, but there was no consistency on occasions. As has been already pointed out, there had been little time for the lime to exert an effect, and the rather heavy dressing applied had not worked down to any considerable extent; these facts, however, do not afford an explanation of the depressing effect on dry-matter yield that lime appears to have exerted on three of the five cutting occasions. Except in the period June 10–July 8, sulphate of iron had a markedly adverse effect on yield, damage to the herbage being very obvious; although there was no localized burning, there appeared to have been a selective killing of species, with the result that the sward became very open. Dawson and Evans [16] have stated that certain species (the fescues) stand up to sulphate of iron better than the other graminaceous components of a mixed sward, and suggest that this is due to its effect in rendering phosphoric acid less available, and thereby impoverishing the soil. It seems doubtful whether damage to particular species can be explained on these grounds. The narrow fescue leaf should be less susceptible to damage than the foliage of such broad-leaved species as the rye-grasses; and the effects produced by sulphate of iron are so rapid that damage would not be likely to result from the inactivation of even a high percentage of the soil phosphate.

From the foregoing, it follows that the application of sulphate of ammonia has been very effective in increasing the yield of carotene, that carbonate of lime has had little influence, and that sulphate of iron has acted adversely. The effects of the first and last of these treatments are evident not only in the mean yields of carotene for the season, but on every cutting occasion.

As will be seen from the first section of Table 3, the mean yield of dry matter on June 10 was high. The following three cuts produced substantially lower yields, but followed no particular trend, whilst the mean yield for the last cut was much lower than on any other occasion. The yields for three of the individual treatments showed this same seasonal variation, and plots receiving carbonate of lime differed only in that yields fell consistently from first to last.

In consequence of these seasonal changes in dry-matter yield, the yield of carotene undergoes comparatively little variation from month to month, despite the fact that the actual carotene-content of the grass rises steadily as the season advances; this applies almost equally well to all treatments.

The authors were not concerned directly with the content of protein in the grass produced under the various treatments applied, but determined this constituent to find out whether there existed a correlation with carotene. It may be noted here, however, that sulphate of ammonia produced grass of a higher crude-protein content, and a greater weight of crude protein per acre, than any other treatment. Sulphate of

iron and carbonate of lime appeared to be without appreciable effect on content or yield of protein. Seasonal variation followed the usual course.

Effect of age at cutting.—The results obtained from the four unmanured plots cut at intervals of 1, 2, 3, and 4 weeks are given in full in the Appendix, and summarized in Table 4. Yields of dry matter, carotene, and crude protein as shown in the latter are totals for the whole experimental period; contents of carotene and crude protein are means for the same period.

TABLE 4. *Summary of Yields, and Contents of Carotene and Crude Protein*

Age in weeks:	*1*	*2*	*3*	*4*
Dry matter (lb. per acre)	1,661	1,804	2,408	2,326
Carotene (mg. per cent. of dry matter)	47·6	49·5	37·8	47·1
Carotene (lb. per acre)	0·705	0·853	0·798	1·053
Crude protein (per cent. of dry matter)	23·40	21·91	21·33	19·83
Crude protein (lb. per acre)	385	394	504	456

It will be seen that the mean carotene-contents of grass from plots cut at intervals of 1, 2, and 4 weeks do not differ appreciably, but that grass of 3 weeks' growth is an exception. Although the site of the plots was carefully chosen, the experiment was subject to all the limitations which attach to any single plot lay-out, and it appears probable that the results obtained have been to some extent affected by soil heterogeneity. The dry-matter yield from the plot cut every three weeks suggests that it has produced quantity rather than quality; dry-matter yields normally increase with the intervals between cuttings. Although these results do not justify any but the most tentative conclusions, they do appear to indicate that the carotene-content of pasture grass suffers no serious depreciation up to an age of 4 weeks.

In view of the small differences in carotene-content, it is obvious that yields of carotene are more or less directly related to the amounts of dry matter produced, and will increase with age up to at least 4 weeks. Under practical conditions intensively-managed grass is not usually grazed within a period of less than 4 weeks after laying up. Furthermore, grass which is to be dried artificially is very rarely cut before this age. The results suggest that from the standpoint of content and yield of carotene, earlier utilization would be of no advantage.

The values for crude protein shown in Table 4 are not of particular interest. Percentage of crude protein in dry matter follows the normal course, and yield is linked up with dry-matter production. As yield of dry matter increases more rapidly than crude protein-content declines, there is a tendency for protein yields to increase as the growth-interval lengthens.

Correlation of carotene with crude protein.—Watson [19] has stated that the carotene-content of artificially-dried grass is closely related to the crude protein. From an examination of 69 samples containing crude

protein contents varying from 9 to 20 per cent. (average 15·1), and carotene covering a range of 10·4 mg. to 48·8 mg. per 100 g. (average 25·8 mg.), this worker obtained a correlation coefficient of +0·816, a highly significant value (odds of 100–1 need 0·302). On the other hand, Ling [20] has examined 33 samples of dried grass from the Bristol and Newcastle areas, and concluded that 'there is little relationship between total crude protein and carotene content'. It should be noted, however, that whereas Watson's results refer to dried grass immediately after baling, Ling's conclusions were based on the examination of samples of which some at least had been stored. That carotene-content is subject to loss varying with the conditions of storage, is well known. Forty-six of the samples taken in the course of the present investigation provided a significant correlation coefficient of +0·530 (odds of 100–1 need 0·372).

As the samples examined showed relatively slight variation in crude-protein content, the highest degree of correlation was not to be expected. Results from samples obtained during the first month of the experimental period were not used for the purpose of the above calculation since carotene–xanthophyll ratios were assumed for these samples, no partitions being made.

Carotene–xanthophyll ratio.—In recent work on dried grass it has been generally assumed that 1 part of carotene is present to every 2 parts of xanthophyll, and carotene-content has been calculated on this basis from the total carotenoids found. Ferguson and Bishop [9] have stated that the ratio in fresh grasses is fairly constant at 1–2·1. Although separations of the two pigments were made on all samples taken after the first month of the experimental period, the ratios found have not been stated. It may therefore be of interest to note that the relative proportions of carotene and xanthophyll did not vary to any considerable extent, and that in the great majority of samples the ratio was approximately 1–2·5.

Summary

The effects of certain fertilizers, and of age at cutting, on the carotene-content of grass from a permanent pasture at Cockle Park, have been investigated.

Sulphate of ammonia, applied at monthly intervals, produced marked increases in the carotene-content of the grass, in the yields of dry matter, and in the yields of carotene. Sulphate of iron, also applied monthly, but at a lower rate than in greenkeeping practice, was without effect on carotene-content, and seriously reduced yield of dry matter. A single dressing of carbonate of lime, which was more than sufficient to satisfy the lime requirement of the soil, produced an increase in carotene-content so small as to be of doubtful significance. An adverse effect on dry-matter yield was noted on three of the five cutting occasions.

There was a marked and fairly consistent rise in the carotene-content of grass produced under all treatments, throughout the experimental period. Attention has been drawn to the practical significance which may attach to this seasonal trend.

The results obtained from samples cut at various stages of growth

were not considered conclusive, but suggest that carotene-content does not vary substantially during a growth period of four weeks.

The carotene content of the grass was found to be related to the percentage of crude protein present, a correlation coefficient of +0·530 being calculated (odds of 100–1 require 0·372).

A majority of the samples proved to have a carotene-xanthophyll ratio of approximately 1–2·5.

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APPENDIX

Yields of Dry Matter, Carotene and Crude Protein, Contents of Carotene and Crude Protein, throughout the Experiment

Age at cutting	*Date of cutting*	*Dry matter (lb. per acre)*	*Carotene (mg. per cent. of dry dry matter)*	*Corotene (lb. per acre)*	*Crude protein (per cent. of dry matter)*	*Crude protein (lb. per acre)*
1 week	May 20	238	22·6	0·054	20·11	47·9
	27	123	41·3	0·051	24·46	30·1
	June 3	170	28·6	0·049	24·58	41·8
	10	75	46·3	0·035	24·80	18·6
	17	76	40·8	0·031	25·13	19·0
	25	72	35·9	0·026	24·77	17·7
	July 1	69	51·2	0·053	23·33	16·1
	8	72	48·3	0·035	22·43	16·2
	15	51	40·6	0·021	23·04	11·8
	22	75	48·7	0·037	21·67	16·2
	29	104	45·7	0·048	22·17	23·1
	Aug. 5	91	42·1	0·038	23·55	21·5
	12	75	41·3	0·031	22·27	16·7
	19	42	45·7	0·019	22·96	9·5
	26	58	61·3	0·035	21·10	12·1
	Sept. 2	75	63·0	0·047	24·62	18·5
	9	79	51·0	0·040	25·43	20·1
	16	54	53·0	0·029	24·59	13·4
	23	36	69·4	0·025	22·14	8·0
	30	27	75·7	0·020	24·94	6·7
2 weeks	May 27	235	42·3	0·100	22·21	52·2
	June 10	200	43·0	0·086	20·73	41·4
	25	223	37·6	0·084	23·53	52·5
	July 8	160	45·1	0·072	19·76	31·5
	22	225	47·9	0·108	20·90	47·1
	Aug. 5	189	39·4	0·075	20·81	39·4
	19	187	41·3	0·077	21·77	40·8
	Sept. 2	138	66·0	0·091	22·88	31·5
	16	131	49·2	0·065	22·80	29·9
	30	116	83·6	0·097	23·72	27·6
3 weeks	June 3	979	22·1	0·216	20·14	197·1
	25	236	26·6	0·063	23·61	55·8
	July 15	164	32·8	0·054	20·09	33·0
	Aug. 5	283	19·2	0·054	20·39	57·6
	26	252	52·4	0·132	20·51	51·8
	Sept. 16	295	59·4	0·175	21·10	62·1
	Oct. 7	199	51·8	0·103	23·48	46·8
4 weeks	June 10	570	34·3	0·196	18·35	104·6
	July 8	512	41·1	0·211	19·18	98·3
	Aug. 5	422	39·4	0·166	19·50	82·3
	Sept. 2	515	52·8	0·272	19·92	102·6
	Sept. 30	307	68·1	0·209	22·19	68·1

DEVELOPMENT OF LIVE STOCK IN TANGANYIKA TERRITORY

III. SKELETAL MEASUREMENTS OF LOCAL FAT-TAILED AND GRADE BLACK-HEADED PERSIAN SHEEP

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1. SKELETAL development in sheep is intimately associated with ultimate body-conformation and mutton capabilities because muscle-length is determined by the length of the supporting bones. An attempt was described in an earlier publication [1] to study the proportional distribution of muscle, fat, and bone in the joints and carcasses of local long-tailed and ¾-grade Black-headed Persian sheep, and the opportunity was taken of studying the more important bones of these skeletons. This paper summarizes these data, but for details of the animals and breeds the previous paper should be consulted.

2. Although there are variations in the rates of development of the different bones, the skeletal structures in general have an earlier phase of development than the muscular or fatty tissues. For this reason the skeleton is likely to be affected to a less extent by adverse nutritional conditions during life than the later-maturing fleshy parts, and so it was thought that skeletal measurements would constitute a method of checking the results of carcass dissections. By comparing the bony structures of the local long-fat-tailed sheep with its Persian crosses it is possible to see what degree of improvement has been effected by introducing Persian blood into our native flocks, and to what extent both breeds fall short of the ideal mutton animal. As there can be very few records in the literature dealing with the skeletal development of fat-tailed sheep (and certainly none are known here), it is hoped that the publication of these measurements will serve a useful purpose.

Material and Methods

3. The animals used in this study are the same as those referred to in the earlier paper [1]. All weights are those of the fresh bones, but the linear measurements were made on degreased bones. The system of measuring and recording used here is the same as that used by Hammond [2], and this work is modelled on his more intensive study of British sheep.

Results

4. Table 1 (p. 249) gives the weights of the bones together with their weight expressed as a percentage of the average cannon-bone weight (metatarsals and metacarpals).

The bone-weights of the local and ¾-grade sheep do not differ markedly, although those bones which have the greatest post-natal development appear slightly heavier in the local breed. As would be expected,

these bone-weights resemble those of the unimproved rather than those of the improved British breeds examined by Hammond. The cannon bones are used as the standard of reference because they have the smallest post-natal development of the bones measured in this study, and for the local sheep their weights lie between those of the Soay and Shetland rams examined by Hammond. With only two exceptions, the other bones of our local and grade sheep are smaller than those of the Shetland in actual weights and in percentages of the cannon bones, whilst the skull, pelvis, sternum, and the cervical, thoracic, and lumbar vertebrae are all very much smaller both actually and relatively. The two exceptions are (i) the tibia-fibula, which has the same weight and relative development as the Shetland, and (ii) the lower jaw, which has a heavier relative weight than in either of the improved or unimproved breeds studied by Hammond.

5. Tables 2 to 7 give the linear measurements of the different bones of the local and grade sheep and the corresponding figures obtained by Hammond for improved and unimproved breeds. Table 8 shows the linear and weight relationships of the shoulder and leg bones. As in the case of the weights, there do not appear to be any differences in the linear measurements of the bones between local and grade Persian sheep. Compared with improved and unimproved British breeds our sheep have smaller cranial depths, shorter spinous processes to the thoracic vertebrae, slightly shallower vertebral bodies, and narrower pelves. The majority of the other bone measurements are intermediate between those of the Soay and Shetland rams examined by Hammond. The metatarsals and metacarpals are longer than in the unimproved British breeds and resemble more closely the Merino and Suffolk rams reported upon by Hammond. The tibia-fibula and radius-ulna resemble the cannon bones in this respect, but to a smaller extent. This greater length of the lower leg and shoulder bones, whilst accentuating the poorly developed thin limbs and making the animals appear very high off the ground, is an adaptation to their hard conditions of life in that it aids rapid movement of the limbs and ability to travel long distances. Another obvious adaptation is the relatively massive lower jaw.

6. The cannon bones of our sheep have weights intermediate between the unimproved breeds examined by Hammond, but a greater length; this confirms the general impression that our animals have very fine bones. The figures in Table 8 indicate that the later-developing bones (femur, humerus, and scapula) are relatively lighter than in the unimproved British breeds and again confirm the thin-boned nature of our sheep.

Discussion

7. Hammond has shown that improvement of British breeds for mutton purposes has resulted not only in increased size but also in an increase of skeletal weight. The latter has been caused by a greater thickening of the bones and by a greater development of those bones which show the greatest and the most delayed post-natal growth. The figures obtained in the above study indicate that both the local long-

fat-tailed sheep and the ¾-grade Black-headed Persian resemble the unimproved types of British sheep in skeletal development, and, since the bony structure limits muscular and fatty developments, the need for improving our local types is very obvious. The results obtained indicate that there is no extra thickening or any greater development of the upper bones in the limbs, nor of the pelvis, and lumbar and sacral vertebrae in grade Persian sheep when compared with our local type. As it is around these bones that the greatest improvement in muscular development can take place, it appears that the introduction of Persian blood into our flocks cannot have caused any significant improvement in the mutton capabilities of our local sheep. This result is in complete agreement with the results of carcass dissections reported upon previously.

Summary

Weights and linear measurements of the bones of local long-fat-tailed sheep and of ¾-grade Black-headed Persian crosses are presented.

These sheep resemble the unimproved British breeds in their skeletal development but possess finer and lighter bones. The lower jaw is the only part of the skeleton which has a greater proportional development (when compared with cannon-bone weight) than in either improved or unimproved British sheep.

The cannon bones are longer in these sheep than in unimproved British breeds, whilst the depth of cranium, length of thoracic vertebral spines, and width of pelvis are all shorter.

The skeletal measurements indicate that grading up local long-tailed sheep with Black-headed Persians is not likely to improve the conformation and mutton capabilities.

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TABLE 1. *Average Weights of the Bones and their Percentage of the Average Cannon Bones*

Animal:	*1 Native*	*2 Grades*	*2 Natives*	*3 Grades*	*1 Native*	*Shetland ram**	*Suffolk ram**
							4 years

TABLE 1. *Average Weights of the Bones and their Percentage of the Average Cannon Bones*

Animal:	*1 Native*		*2 Grades*		*2 Natives*		*3 Grades*		*1 Native*		*Shetland ram**		*Suffolk ram**	
Age:	*1½ years*		*1½ years*		*2–2½ years*		*2–2½ years*		*5 years*		*5 years*		*4 years*	
	Gm.	Per cent.	Gm.	Per cent.	Gm.	Per cent.	Gm.	Per cent.	Gm.	Per cent.	Gm.	Per cent.	Gm.	Per cent.
Skull	444	1,306	302	959	434	1,335	464	1,450	500	1,538	943	2,858	1,155	1,367
Lower jaw	126	371	115	365	164	505	139	434	147	452	133	403	288	341
Scapula	37	109	33	105	44	135	39	122	49	151	61	185	216	256
Humerus	65	191	63	200	76	234	68	213	71	218	87	264	243	288
Radius-ulna	56	165	53	168	62	191	56	175	61	188	64	194	198	234
Metacarpal	33	97	32	101	30	92	31	97	32	99	32	97	84	99
Femur	80	235	80	254	94	289	81	253	88	271	100	303	288	341
Tibia-fibula	77	226	76	241	84	258	76	238	81	249	84	255	243	288
Metatarsal	35	103	31	99	35	108	33	103	33	101	34	103	85	101
Pelvis	90	265	98	311	120	369	90	281	122	375	143	433	520	615
Ribs	204	600	175	555	268	825	222	694	313	963	363	1,100	1,215	1,438
Sternum	28	82	30	95	41	126	36	113	50	154	56	170	218	258
Costal cartilages	32	94	42	133	33	101	36	113	39	120	..	..	..	..
Vertebrae cervical	144	424	133	422	192	591	179	559	238	732	314	952	717	849
,, thoracic	137	403	111	352	177	545	145	453	197	606	238	721	651	771
,, lumbar	118	347	95	302	128	394	106	331	144	443	157	476	533	631
,, sacral	40	118	30	95	41	126	32	100	55	169	48	145	145	172
,, caudal	19	56	10	32	16	49	11	34	19	58	12	36	35	41

* From Hammond's figures.

TABLE 2. *Linear Dimensions of the Skull*

Animals	*Length of skull* (mm.)	*Expressed as per cent. of skull-length*		
		Depth of cranium	*Width of eyes*	
			Outside top of eye orbit	*Inside bottom of eye orbit*
1 Native, 1½ years	210	32·9	46·7	36·7
2 Grades, 1½ years	196	31·6	47·4	37·5
2 Natives, 2–2½ years	209	31·3	48·1	36·8
3 Grades, 2–2½ years	204	30·9	50·1	38·1
1 Native, 5 years	232	32·1	45·9	40·9
Suffolk ram, 4 years*	288	38·2	52·3	33·9
Shetland ram, 5 years*	218	43·6	53·7	34·4
Merino ram, 5 years*	259	36·3	47·9	32·0
Soay, ram 1–2 years*	182	46·2	53·8	38·5

* From Hammond's figures.

TABLE 3. *Average Linear Dimensions of Vertebrae*

Animals	Cervical vertebrae				Thoracic vertebrae			Lumbar vertebrae				
	Average length of No. 3–7 (mm.)	Transverse process as per cent. of vertebral body-length			Average length of vertebral bodies (mm.)	Per cent. of vertebral body-length		Average length of vertebral bodies (mm.)	Per cent. of vertebral body-length			
		Atlas	Axis	Nos. 3–7		Depth of average vertebral body	Length of average spinous process		Width of average vertebral body	Depth of average vertebral body	Height of average spinous process	Length of average transverse process
1 Native, 2 Grades, 1½ years	32	182	117	124	20	62	317	26	82	45	69	313
	25	224	148	169	19	63	257	26	85	45	72	294
2 Natives, 3 Grades, 2–2½ years	31	187	144	152	20	73	273	27	87	51	103	323
	25	232	156	187	20	67	238	26	88	47	75	307
1 Native, 5 years	39	180	123	142	20	81	317	24	60	65	101	356
Suffolk ram, 4 years*	35	308	107	217	26†	95	363	39‡	80	66	98	374
Shetland ram, 5 years*	29	300	90	203	20†	85	462	34‡	63	48	81	289
Merino ram, 5 years*	31	315	107	208	22†	92	469	30‡	89	67	93	419
Soay ram, 1–2 years*	24	223	78	171	17†	72	377	26‡	72	51	75	305

* From Hammond's figures. † Values for the first six vertebrae only. ‡ Values for 3rd, 4th, and 5th lumbar vertebrae only.

TABLE 4. *Linear Dimensions of the Ribs and Sternum*

Animals	Ribs 1 to 5			Ribs 6, 7, and 8			Ribs 9 to 13			Sternum	
	Average length (mm.)	As per cent. of length		Average length (mm.)	As per cent. of length		Average length (mm.)	As per cent. of length		Length (mm.)	Maximum width as per cent. of length
		Spring	Width		Spring	Width		Spring	Width		
1 Native, 2 Grades, 1½ years	131	17·1	9·7	172	20·9	7·1	145	20·6	5·4	140	21·4
	133	16·5	10·7	175	22·6	7·4	149	21·5	4·4	152	21·0
2 Natives, 3 Grades, 2–2½ years	145	12·9	9·9	188	20·2	6·8	163	19·9	4·7	178	21·1
	137	16·0	10·4	179	23·2	7·0	149	20·9	4·9	164	21·2
1 Native, 5 years	134	17·1	12·6	175	23·5	8·4	155	23·9	5·8	154	23·8
Suffolk ram, 4 years*	..	..	..	221	24·2	12·4	..	..	..	254	29·7
Shetland ram, 5 years*	..	..	..	190	22·1	8·6	..	..	..	189	20·1
Merino ram, 5 years*	..	..	..	210	24·5	11·0	..	..	..	220	25·0
Soay ram, 1–2 years*	..	..	..	153	19·8	7·8	..	..	..	161	25·5

* From Hammond's figures.

TABLE 5. *Linear Dimensions of the Pelvis*

										161	25·5

• From Hammond's figures.

TABLE 5. *Linear Dimensions of the Pelvis*

Animals	*Length* (mm.)	*Width as per cent. of length*
1 Native, 2 Grades, 1½ years	162 174	28·2 24·0
2 Natives, 3 Grades, 2–2½ years	177 175	26·2 25·7
1 Native, 5 years	157	30·3
Suffolk ram, 4 years•	268	29·3
Shetland ram, 5 years•	201	30·8
Merino ram, 5 years•	227	27·8
Soay ram, 1–2 years•	165	29·1

• From Hammond's figures.

TABLE 6. *Linear Dimensions of the Chief Bones of the Shoulder*

Animals	*Scapula*			*Humerus*		*Radius-ulna*		*Metacarpal*	
	Length (mm.)	*Width as per cent. of length*	*Width under spine as per cent. of width above*	*Length* (mm.)	*Circumference as per cent. of length*	*Length* (mm.)	*Circumference as per cent. of length*	*Length* (mm.)	*Circumference as per cent. of length*
1 Native, 2 Grades, 1½ years	131 137	70·7 58·2	373 347	135 139	39·6 36·0	200 201	23·9 21·6	137 139	31·0 28·0
2 Natives, 3 Grades, 2–2½ years	138 142	63·8 58·0	387 331	141 142	39·9 36·8	193 204	26·6 21·8	124 131	37·2 31·5
1 Native, 5 years	135	68·4	270	137	38·8	185	25·3	120	39·8
Suffolk ram, 4 years•	191	77·7	340	187	46·0	230	35·4	135	50·9
Shetland ram, 5 years•	150	64·0	444	151	37·1	192	26·6	125	34·4
Merino ram, 5 years•	165	66·1	460	158	41·1	204	29·4	130	37·7
Soay ram, 1–2 years•	122	61·5	369	129	36·4	166	25·9	115	33·9

• From Hammond's figures.

TABLE 7. *Linear Dimensions of the Chief Bones in the Leg*

Animals	Femur		Tibia-Fibula		Metatarsal	
	Length (mm.)	Circumference as per cent. of length	Length (mm.)	Circumference as per cent. of length	Length (mm.)	Circumference as per cent. of length
1 Native, 2 Grades, 1½ years	164	31·5	214	21·0	138	29·7
	172	28·8	213	21·1	149	28·9
2 Natives, 3 Grades, 2–2½ years	167	34·6	200	24·6	133	32·3
	170	30·4	210	21·6	142	28·5
1 Native, 5 years	162	31·5	192	34·5	130	28·5
Suffolk ram, 4 years*	220	39·5	242	29·3	141	45·0
Shetland ram, 5 years*	180	30·6	210	21·4	132	31·8
Merino ram, 5 years*	192	33·9	223	25·1	138	33·3
Soay ram, 1–2 years*	156	30·1	189	21·7	125	31·2

* From Hammond's figures.

TABLE 8. *Linear and Weight Relationships of the Shoulder and Leg Bones*

Animals	Shoulder								Leg					
	Metacarpal length (mm.)	As per cent. of Metacarpal length			Metacarpal weight (gm.)	As per cent. of Metacarpal weight			Metatarsal length (mm.)	As per cent. of Metatarsal length		Metatarsal weight (gm.)	As per cent. of Metatarsal weight	
		Scapula length	Humerus length	Radius-ulna length		Scapula weight	Humerus weight	Radius-ulna weight		Femur length	Tibia-fibula length		Femur weight	Tibia-fibula weight
1 Native, 2 Grades, 1½ years	137	96	99	146	33	113	199	172	138	119	155	35	229	223
	139	99	100	145	32	103	202	168	149	116	143	31	263	248
2 Natives, 3 Grades, 2–2½ years	129	107	109	149	30	146	251	204	133	126	151	34	278	249
	131	108	108	154	31	125	217	181	142	120	148	33	247	231
1 Native, 5 years	120	111	114	155	28	154	243	206	130	124	148	30	275	257
Suffolk ram, 4 years*	136	141	138	170	84	260	291	232	141	156	172	85	340	280
Shetland ram, 5 years*	125	120	121	154	33	186	266	195	132	136	159	34	296	250
Merino ram, 5 years*	130	127	122	157	..	..	..	..	138	139	162	..	..	..
Soay ram, 1–2 years*	115	106	112	144	25	137	216	195	125	125	151	26	265	247

* From Hammond's figures.

INFLUENCE OF SIZE OF SEED AND SPACING ON THE YIELD OF KING EDWARD VII POTATOES

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Introduction.—The results of a one-year trial, conducted in 1934 on a silt soil in Norfolk, in which the effects on King Edward VII potatoes of size of seed and spacing were studied, has already been reported by Bates [1]. The investigation was continued in 1935 and 1936 by the authors, and in this paper the results of the three-years' yield trials are summarized.

The general technique adopted for the trials was the same each year and was described by Bates [1]. Each trial was situated in a field of potatoes grown on a medium silt soil on the farm of Mr. C. W. Cave, Terrington St. Clement. King Edward VII seed from Scotland, sprouted under glass, was used, and before boxing the seed was divided by riddling into the following three grades:

1. Small seed, on 1¼ in. through 1⅜ in. riddle; average weight 1·0 oz.
2. Medium seed, on 1⅜ in. through 1⅝ in. riddle; average weight 1·5 oz.
3. Large seed, on 1⅝ in. through 2 in. riddle; average weight 2·5 oz.

The potato rows were 29 in. apart and the spacing distances adopted were 12, 15, 18, and 21 in., arranged in a 4×4 Latin square. Each plot was split into three sub-plots for size of seed, the harvested area of each being 1/300 acre.

At lifting the produce from each sub-plot was dressed by riddling into the following grades and weighed:

1. Ware, on 1⅝ in. riddle.
2. Large ware, on 2¼ in. riddle.
3. Seed, on 1¼ in. through 1⅝ in. riddle.
4. Chats, through 1¼ in. riddle.

An estimate of the size of the individual tubers of the large-ware grade was obtained in 1934 by weighing a random sample of 50 large-ware tubers per sub-plot, and in the two succeeding years by counting and weighing all the large-ware tubers on each sub-plot. The results are expressed as 'average weight per tuber of large ware'.

In the 1935 and 1936 trials the seed was sown on March 20 and April 1, and the tubers lifted on October 1 and September 15, respectively.

The following observations were made on the growth of the crops:

1935. A sharp frost occurred on May 17 after the potato shoots had appeared above ground. The effects of the frost were not serious, however, though as a result of fresh growth the haulms were more branched than usual. A dry summer followed, and at the end of August the crop was suffering from lack of moisture. A considerable amount of the virus disease 'Leaf Drop Streak' developed and appeared to be most abundant on the plots planted with large seed. At the end of August these plots could be picked out clearly owing to their apparently

• From Hammond's figures.

much greater degree of infection with virus disease. A possible explanation is that the greater competition for moisture among the plants arising from large setts may have intensified the visual effects of the virus disease on the foliage. It seems improbable that the amount of virus infection was actually greater with large seed. A small amount of late blight (*Phytopthora infestans*) infection appeared early in September and the crop was therefore sprayed with sulphuric acid to kill the haulm 11 days before lifting.

1936. A cold spell followed planting and early growth was slow. Warm, showery weather followed in which the haulms grew very quickly. In spite of the usual spraying precautions the crop was attacked by blight early in July. The continued wet weather was favourable to the spread of the disease, and the haulm was killed completely by the end of August. The incidence and spread of the disease were not influenced by the greater crowding where the seed was planted closely, or where large seed was used.

In both years the apparent greater vigour of growth on the large-seed plots, referred to by Bates [1], was noticed.

Mean Yields for Three Years, 1934–6

The average results for the three years 1934–6 are given in Tables 1–7; the yields for 1935 and 1936 are given separately in Appendixes I and II. The form of analysis of variance used for calculating the significant differences in Tables 1–7 was as follows:

	Degrees of freedom		*Degrees of freedom*
Rows	9	Seed-size	2
Columns	9	Inter-actions:	
Spacing distance	3	Seed-size × spacing distance	6
Years	2	Seed-size × years	4
Interaction:		Seed-size × years × spacing distance	12
Spacing distance × years	6	Error (*b*)	72
Error (*a*)	18	Total	143
Sub-total	47		

All values for significant difference have been calculated from Fisher's [2] table of *t*, with P = 0·05.

TABLE 1. *Total Yield of Potatoes* (*tons per acre*)

Seed-size	*Spacing distances* (*in.*)				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅝ in.	10·7	10·4	9·7	9·4	10·05
Medium, 1⅝ to 1⅞ in.	11·2	11·2	10·1	10·1	10·65
Large, 1⅞ to 2 in.	11·8	11·7	11·4	11·0	11·48
Mean	11·23	11·10	10·40	10·17	10·73

Significant differences:

Seed-size (mean of all spacing distances): 0·36 tons.
Spacing distance (mean of all seed-sizes): 0·49 tons.

TABLE 2. *Yield of Ware over 1⅝ in. (tons per acre)*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in.	8·9	8·8	8·4	8·4	8·62
Medium, 1⅜ to 1⅝ in.	9·3	9·5	8·8	8·8	9·10
Large, 1⅝ to 2 in.	9·7	10·1	10·0	9·7	9·87
Mean	9·30	9·47	9·07	8·97	9·20

Significant differences:

Seed-size (mean of all spacing distances): 0·33 tons.
Spacing distance (mean of all seed-sizes): 0·47 tons.

TABLE 3. *Yield of Large Ware over 2¼ in. (tons per acre)*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in.	3·5	4·1	4·0	4·0	3·90
Medium, 1⅜ to 1⅝ in.	3·4	3·6	4·0	4·3	3·82
Large, 1⅝ to 2 in.	3·1	3·9	4·2	4·4	3·90
Mean	3·33	3·87	4·07	4·23	3·87

Significant differences:

Seed-size (mean of all spacing distances): 0·25 tons.
Spacing distance (mean of all seed-sizes): 0·36 tons.

TABLE 4. *Average Weight per Tuber of Large Ware (ounces)*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in.	7·5	8·3	8·5	9·0	8·32
Medium, 1⅜ to 1⅝ in.	7·2	7·3	8·5	8·6	7·90
Large, 1⅝ to 2 in.	6·9	7·3	7·7	7·8	7·42
Mean	7·20	7·63	8·23	8·47	7·88

Significant differences:

Seed-size (mean of all spacing distances): 0·58 oz.
Spacing distance (mean of all seed-sizes): 0·67 oz.

TABLE 5. *Large Ware expressed as Percentage of Total Yield*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in.	33·3	38·7	40·2	43·0	38·8
Medium, 1⅜ to 1⅝ in.	31·0	32·5	39·4	41·8	36·2
Large, 1⅝ to 2 in.	26·7	34·1	36·7	39·7	34·3
Mean	30·3	35·1	38·8	41·5	36·4

Significant differences:

Seed-size (mean of all spacing distances): 1·9 per cent.
Spacing distances (mean of all seed-sizes): 3·1 per cent.

TABLE 6. *Yield of Seed 1¼ to 1⅝ in. (cwt. per acre)*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in. . .	28	26	21	16	22·7
Medium, 1⅜ to 1⅝ in. . .	30	25	21	19	23·8
Large, 1⅝ to 2 in. . .	32	26	24	22	26·0
Mean	30·0	25·7	22·0	19·0	24·0

Significant differences:

Seed size (mean of all spacing distances): 1·9 cwt.
Spacing distances (mean of all seed-sizes): 3·1 cwt.

TABLE 7. *Yield of Chats through 1¼ in. riddle (cwt. per acre)*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in. . .	8	6	6	5	6·2
Medium, 1⅜ to 1⅝ in. . .	8	9	5	6	7·0
Large, 1⅝ to 2 in. . .	9	6	5	5	6·3
Mean	8·3	7·0	5·3	5·3	6·5

Significant differences:

Seed-size (mean of all spacing distances): 1·0 cwt.
Spacing distance (mean of all seed-sizes): 1·4 cwt.

General Conclusions

The conclusions reached by Bates [1] from the results of a single year's trial have largely been confirmed.

Effect of seed-size.—The total yield and the yields of total ware and of seed potatoes were greater from large seed than from medium seed. Medium seed also gave heavier yields of these grades of produce than small seed. Size of seed did not influence the yield of large ware potatoes, but small seed produced an increase in the size of the individual tubers of this grade. The smallest percentage (by weight) of large ware was produced from large seed, and, as the total crop from large seed exceeded that from small seed or medium seed, it may be assumed that large seed gave rise to a greater number of tubers than small or medium seed. This was shown to be so by Bates (1) at 15 in. spacing. Table 9 shows that in 1936 also there were differences in the total number of tubers per 'hill' produced by each size of seed. An explanation of this difference in behaviour between the three sizes of seed has been offered by Bates [1].

Effect of spacing distance.—Increase in the spacing distance produced (*a*) a reduction in total yield and in the yields of the seed and chat grades, (*b*) an increase in the yield and in the percentage (by weight) of the large-ware grade and in the size of the individual tubers of this grade, (*c*) a small decrease which was not significant in the yield of total ware.

Within the limits of the trial the effect of spacing on yield appeared

to vary with the size of the seed, for as the spacing distance was increased the reductions in total yield and in the yield of total ware were less from large seed than from small seed. No significant interactions between size of seed and spacing distance have been found in any of the Tables.

The reduction in the yield of small potatoes and the increases in the yield of large ware, and in the size of the individual large-ware tubers, indicate that an essential consequence of increasing the spacing distance was to increase the average size of the tubers as a whole. This was found to be so in 1936, when a record of the total number of tubers per sub-plot was made. Table 8 shows that in 1936 there was a significant increase in the average weight per tuber between 12 and 15 in. spacing and between 15 and 21 in. spacing. Seed-size, on the other hand, did not significantly influence the average size of all the tubers.

TABLE 8. *Average Weight per Tuber in 1936 (ounces)*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in. . .	2·67	2·93	3·15	3·56	3·08
Medium, 1⅜ to 1⅝ in. . .	2·78	3·05	3·09	3·06	2·99
Large, 1⅝ to 2 in. . .	2·53	3·03	3·21	3·38	3·04
Mean	2·66	3·00	3·15	3·33	3·04

Significant differences:

Seed-size (mean of all spacing distances): 0·18.
Spacing distance (mean of all seed-sizes): 0·28.

A further effect of spacing in 1936 was to influence the number of tubers at each 'hill'. This is shown in Table 9, and it will be noted that 12-in. spacing produced significantly fewer tubers per hill than 21-in. spacing. There was, however, no significant difference between 12-in. and 15-in. spacing, between 15-in. and 18-in. spacing, or between 18-in. and 21-in. spacing.

TABLE 9. *Total Number of Tubers per 'Hill' in 1936*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in. . .	7·88	8·65	8·30	8·73	8·39
Medium, 1⅜ to 1⅝ in. . .	8·22	9·05	9·43	10·17	9·22
Large, 1⅝ to 2 in. . .	9·07	10·40	10·05	10·93	10·11
Mean	8·39	9·37	9·26	9·94	9·24

Significant differences:

Seed-size (mean of all spacing distances): 0·58.
Spacing distance (mean of all seed-sizes): 1·09.

The increase in the number and size of the tubers with wide spacing did not compensate for the reduction in the number of plants, and therefore there was a reduction in the total yield as the spacing distance was increased.

Practical Considerations

The size of the seed and the spacing distance obviously influence the amount of seed needed to plant an acre. This is shown in Table 10, which has been drawn up for 29-in. rows.

TABLE 10. *Weight of Seed to Plant an Acre (cwt.)*

Seed-size	*Spacing distances (in.)*			
	12	*15*	*18*	*21*
Small, 1¼ to 1⅜ in.	10	8	6¾	5¾
Medium, 1⅜ to 1⅝ in.	15	12	10	8½
Large, 1⅝ to 2 in.	25¼	20	16¾	14½

The seed-requirement per acre must be taken into account when practical application of the results of the trials is considered. In Table 11 therefore, the 'net yield' of the total ware has been calculated, i.e. the yield of ware potatoes (including large ware) less the weight of seed planted. This arbitrary method of allowing for the weight of seed planted can be criticized, but it serves to show the general position and avoids calculations with prices, which fluctuate considerably.

TABLE 11. *'Net Yield' of Total Ware over 1⅝ in. (tons per acre)*

Seed-size	*Spacing distances (in.)*				
	12	*15*	*18*	*21*	*Mean*
Small, 1¼ to 1⅜ in.	8·4	8·1	8·0	8·0	8·12
Medium, 1⅜ to 1⅝ in.	8·5	8·9	8·3	8·4	8·52
Large, 1⅝ to 2 in.	8·4	9·0	9·1	9·0	8·88
Mean	8·43	8·67	8·47	8·47	8·51

Significant differences:

Seed-size (mean of all spacing distances): 0·33 tons.
Spacing distance (mean of all seed-sizes): 0·48 tons.

It will be seen from Table 11 that even when allowance is made for the greater weights of seed needed per acre, large seed and medium seed gave significantly heavier 'net yields' than small seed. The spacing distance, on the other hand, had no significant influence on the 'net yield'. It will be noticed, however, that with small seed, wide spacing produced a decrease in 'net yield', whereas with large seed there was actually an increase in the 'net yield' as the spacing distance was increased. This interaction between size of seed and spacing distance, however, was not significant, though the regression for interaction of seed-size and spacing distance, obtained by division of the interaction SS into regression (1 D.F.) and deviations from the regression (5 D.F.), was significant at the 5 per cent. value of z. This suggests that, in practice, it would be advantageous to grade the seed potatoes into two or possibly three grades, and to vary the spacing distance according to the size of the tubers in each grade. For the three grades used in these trials

the setting distances suggested are 12 in. for the small seed, 15 in. for the medium seed, and 21 in. for the large seed. Division of the seed on these lines would, in certain cases, lead to heavier yields, as compared with planting the mixed seed all the same distance apart. Also, depending upon the proportion of large seed relative to the other grades, there would be some economy in the weight of seed needed per acre.

If practical application is to be made of these results, however, the conditions peculiar to the trials must be borne in mind. For instance, it is open to conjecture if similar results would be obtained with unsprouted seed. Plants from unsprouted seed have a shorter period of growth, and there is a greater risk of unsound seed causing blank spaces in the crop. Similarly, the conclusions apply only to the variety King Edward VII grown on a rich, fertile soil, though it is not unlikely that other varieties would in the main behave in a similar manner.

Summary

Three-year trials (1934–6) with King Edward VII potatoes have shown that on silt soils in Norfolk spacing distance and size of seed influenced the yields of the various grades of potatoes.

Within the limits of the spacing distances adopted (12 to 21 in.), wide spacing reduced the total yield and the yields of seed and chat potatoes, but increased the yields of large ware tubers and the average size of these tubers. The yield of ware potatoes and the 'net yield' of ware were not significantly affected.

Large seed produced the greatest total yield, the greatest 'net yield' of ware, and the greatest yields of ware and seed. Seed-size did not influence the yield of large-ware tubers, but the average size of these tubers was greatest from small seed.

There was some indication that the limit to spacing beyond which the yield fell, varied with the size of the seed.

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APPENDIX I. 1935 RESULTS

SMALL SEED, 1¼ to 1⅜ in.

Spacing distance (in.)	*Total yield (tons)*	*Total ware (tons)*	*Large ware (tons)*	*Seed (tons)*	*Chats (tons)*	*Average weight per large-ware tuber (oz.)*	*Large ware as per cent. of total yield*
12	11·8	9·2	3·3	1·9	0·7	7·1	28·1
15	10·9	8·6	3·9	1·7	0·6	7·4	36·0
18	11·2	9·1	4·4	1·5	0·6	7·6	38·7
21	10·8	9·2	4·7	1·1	0·5	8·0	43·2
			MEDIUM SEED, 1⅜ to 1⅝ in.				
12	12·1	9·5	3·7	1·8	0·8	7·5	30·6
15	12·4	9·9	3·8	1·7	0·8	6·4	30·4
18	10·9	9·0	4·1	1·4	0·5	8·0	37·6
21	11·7	10·0	5·2	1·2	0·5	9·6	43·2
			LARGE SEED, 1⅝ to 2 in.				
12	12·9	10·3	3·6	1·9	0·7	7·2	27·8
15	12·1	9·9	3·9	1·6	0·6	7·6	31·6
18	12·6	10·7	4·8	1·6	0·3	7·5	37·7
21	12·3	10·5	5·3	1·4	0·4	8·2	42·5
			MEAN EFFECT OF SIZE OF SEED				
Small, 1¼ to 1⅜ in.	11·18	9·02	4·08	1·55	0·61	7·8	36·5
Medium, 1⅜ to 1⅝ in.	11·78	9·60	4·20	1·52	0·66	7·9	35·4
Large, 1⅝ to 2 in.	12·48	10·35	4·40	1·62	0·51	7·6	34·9
Sig. diff.	0·90	0·81	0·57	0·24	0·12	1·1	3·9
			MEAN EFFECT OF SPACING DISTANCE				
12 in.	12·27	9·66	3·53	1·87	0·74	7·3	28·6
15 in.	11·80	9·47	3·87	1·67	0·64	7·1	32·7
18 in.	11·57	9·60	4·43	1·50	0·47	7·7	38·0
21 in.	11·60	9·90	5·07	1·23	0·47	8·6	43·0
Sig. diff.	1·02	0·99	1·08	0·42	0·18	1·2	7·0

APPENDIX II. 1936 RESULTS

APPENDIX II. 1936 RESULTS

SMALL SEED, 1¼ to 1⅝ in.

Spacing distance (in.)	*Total yield (tons)*	*Total ware (tons)*	*Large ware (tons)*	*Seed (tons)*	*Chats (tons)*	*Average weight per large-ware tuber (oz.)*	*Large ware as per cent. of total yield*
12	10·4	8·6	0·9	1·5	0·3	7·7	8·1
15	9·9	8·2	1·2	1·5	0·2	8·1	12·1
18	8·7	7·5	1·4	1·0	0·2	8·1	16·1
21	9·1	8·3	1·7	0·7	0·1	8·3	18·2
MEDIUM SEED, 1⅝ to 1⅝ in.							
12	11·3	9·5	1·0	1·6	0·2	6·9	8·5
15	10·9	9·4	1·2	1·3	0·2	7·7	11·1
18	9·6	8·3	1·1	1·1	0·2	9·8	11·2
21	9·0	7·8	1·5	0·9	0·3	8·2	16·7
LARGE SEED, 1⅝ to 2 in.							
12	11·5	9·5	0·9	1·7	0·3	7·2	7·6
15	12·4	10·3	1·9	1·4	0·2	7·3	14·7
18	10·5	9·3	1·5	1·0	0·2	7·7	14·0
21	10·8	9·7	1·9	0·9	0·2	8·0	17·6
MEAN EFFECT OF SIZE OF SEED							
Small, 1¼ to 1⅝ in.	9·52	8·15	1·30	1·17	0·20	8·05	13·6
Medium, 1⅝ to 1⅝ in.	10·20	8·75	1·20	1·22	0·23	8·15	11·9
Large, 1⅝ to 2 in.	11·30	9·82	1·55	1·25	0·23	7·55	13·5
Sig. diff.	0·68	0·75	0·36	0·18	0·50	0·89	2·7
MEAN EFFECT OF SPACING DISTANCE							
12 in.	11·07	9·20	0·93	1·60	0·27	7·27	8·1
15 in.	11·07	9·47	1·43	1·40	0·20	7·70	12·6
18 in.	9·60	8·37	1·33	1·03	0·20	8·53	13·8
21 in.	9·63	8·60	1·70	0·83	0·20	8·17	17·5
Sig. diff.	0·87	0·79	0·64	0·38	0·90	1·15	7·8

SOME OBSERVATIONS ON A DISEASE OF SHEEP ON DARTMOOR

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ATTENTION was called to a peculiar disease of sheep on Dartmoor eighteen months after two flocks of Pedigree Welsh and Shetland sheep were brought to Hedge Barton Farm, Manaton, in 1934. On inquiry it was found that the disease is common to the locality, but confined to an area on the granite soils of the Moor, and that it has been prevalent for many years. It occurs only on certain farms in the locality, or even on certain fields on one farm, and the intensity and rapidity of onset vary from field to field.

Symptoms.—The affected sheep have a general unthrifty appearance: the fleece becomes staring and harsh to the touch, the ears droop, and the face takes on a characteristic 'grey' look. In the early stages the eyes become inflamed. The animals become gradually weaker and emaciated; they stagger and finally lose the use of their legs. After any slight exertion the rate of breathing and of heart-beat increase greatly. On examination after death a general state of malnutrition is found, and the intestines are often infested with parasites, chiefly *Haemonchus contortus* and *Ostertagia circumcincta*. The liver is very fatty and oily [1] and is deficient in mineral matter.

Breed.—All breeds of sheep do not suffer to the same extent. The Welsh breed is very susceptible, and in the autumn of 1935 all the lambs were affected. Shetlands appear to be immune, or much more resistant, as no instance of 'pining' has been found among the flock in five years.

Climate.—The farms on Dartmoor that are most subject to the disease are at an average height of about 1,100 ft. above sea-level. The annual average rainfall is about 60 in. According to local shepherds the trouble is most common in a wet season following a dry one.

Soil.—In Devonshire there seems to be, for want of evidence to the contrary, a connexion between soil and 'pining' in that the disease is found only on granite soils, where the cure is effected by moving sheep to other pastures on soils of very varied geological type. A typical description (abbreviated) of a 'pining' Dartmoor profile is:

0–10 in. . . .	Greyish-brown gritty light loam.
10–21 in. . . .	Slightly yellowish-brown loose light loam. Granite fragments.
21–8 in. . . .	Coarse angular granite brash with large fragments of rock.
28+ in. . . .	Coarse-grained granite.

These soils show no visual evidence of podsolization; they occur on moderately steep slopes, and the constant wash of soil has prevented the development of a mature profile.

Typical mechanical analyses of Dartmoor soils associated with 'pining'

are given below, together with corresponding figures for healthy lowland soils in Devonshire.

The healthy soils derived from shales are decidedly heavier in texture than the 'pining soils', but the Maidencombe conglomerate soil is an exception.

Determinations were made of phosphoric acid soluble in concentrated hydrochloric acid and 2 per cent. citric acid, potash soluble in concentrated hydrochloric acid and N/2 acetic acid, nitrogen, exchangeable calcium, and pH. On the whole, the healthy soils contained more phosphorus and potash, no doubt owing to their being cultivated lowland pastures. There was no significant difference in pH or exchangeable calcium.

TABLE 1. *Mechanical Analysis of Healthy and Unhealthy Soils*

	Sick soils		*Healthy soils*			
Description	*Dartmoor granite*	*Wingstone granite*	*Tigley shale*	*Yelland shale and diabase*	*Beenleigh shale*	*Maidencombe conglomerate*
Coarse sand .	33·73	26·99	9·48	15·48	20·44	30·67
Fine sand . .	21·58	33·97	13·28	9·08	14·19	27·17
Silt . . .	14·30	13·55	24·85	24·20	25·30	16·35
Clay . . .	14·43	17·25	39·05	36·33	24·45	21·38
Loss on ignition .	16·95	13·76	18·52	19·50	22·30	8·18
Loss by solution .	4·46	3·79	3·48	5·39	4·15	2·86

Eleven samples each of healthy and sick soils had a mean content of 2·14 per cent. and 1·43 per cent., respectively, of iron soluble in 5 per cent. oxalic acid. The difference between these means is, however, not statistically significant.

Causes.—Among the suggested possible causes of 'pining' are: (*a*) parasites, (*b*) poisonous plants, and (*c*) mineral deficiency.

The fact that different breeds of sheep are affected in a different manner on the same farm appears to point to nutritional factors rather than to parasites, since, as far as is known, parasitic infestations are not specific to breeds. Similarly, it is unlikely that the poisonous effect of plants on cultivated pastures would be different with the two breeds of sheep.

On the other hand, mineral deficiency, either alone or in combination with parasites, appears to be the most likely cause, and it was investigated first. The rapidity of the recovery of sheep when moved to lowland pastures is striking and is inexplicable on the view that parasites are the sole or principal cause of the poor state of health of the sheep. The parasitic infestation is possibly the result, and not the cause, of the low state of health, which allows a worm-burden tolerated under ordinary conditions to have effects which would normally be resisted. This point requires investigation.

It is possible that the immunity of the Shetland breed may have its roots in the similarity of the climatic and soil conditions of Dartmoor

and the Shetland Islands. Both are fairly high in altitude and have soils of very free drainage on granite. The geological materials from which both areas are formed are very similar, comprising granite, mica- and hornblende-schists, and New Red Sandstone deposits.

The geological materials to be found in north and mid-Wales, on the other hand, consist of shales and limestones similar to those occurring on the lowlands of south Devon.

Cure.—The only apparent cure on Dartmoor is to move the flock for two or three months in the autumn and winter to lowland farms on soils of heavier texture. On certain farms near the edge of the Moor it is claimed that movement of the flock to another field on the same farm, or the feeding of turnips, may bring about a temporary cure.

Similar diseases elsewhere.—Similar symptoms of diseases of sheep known as 'pine' and 'bush-sickness' have been described in recent years by Russell Greig, Dryerre, and others in Tiree [2], M'Gowan and Smith in the Cheviots [3], and Askew and Rigg in New Zealand [4]. In 1794 Fraser [5] described a disease of sheep and cattle on Dartmoor which resembles that described above. The movement of animals to other gound for cure is common to [3], [4], and [5], whilst the feeding of turnips for the same purpose is given by [3] and [5]. Differences in the susceptibility of breeds were noticed in the Cheviots [6], as were also the effects of dry and wet seasons [3]. Similarity in soil conditions are found in New Zealand with regard to texture and parent material [4, 7, 8], and the solubility of iron in 5 per cent. oxalic acid has been used as an index of incidence in New Zealand [9] and in Tiree [2].

Treatment.—As mentioned above, the treatment followed on Dartmoor has been to move the flocks on to lowland pastures for a period. Fraser [5] says that in 1794 an alternative was to give 'drafts of red loam, mixed with water'. It is interesting to note that the giving of a drench of soil from healthy pastures as a cure is the same treatment as that found by New Zealand workers to be effective in the Nelson area [10, 11]. The beneficial effect of feeding sheep with turnips by folding on the growing crop may be ascribed to the ingestion of quantities of soil larger than those which are obtained in the grazing of pasture. The work of Underwood and Filmer [12] called attention to the curative properties of cobalt in the soil, and other workers, in particular Lines [13], Marston [14], and Askew and Dixon [15], have shown the effectiveness of giving cobalt salts as a supplement. Kidson [16] has studied the cobalt-content of New Zealand soils by determining the percentage cobalt extracted by concentrated hydrochloric acid. The variation is wide—0·3 to 380 parts per million. She concludes that, in general, soils affected with stock ailments have comparatively low cobalt-contents, but that there are notable exceptions; and that the determination of the cobalt-content of a soil is not a dependable guide to the necessity for the giving of cobalt supplements to stock.

Experimental

Determinations of the cobalt-content of soils from unhealthy and healthy areas in Devon have been made by the method of Kidson,

Askew, and Dixon [17], and a summary of the results obtained is shown in Table 2. (See also Kidson [18] and Patterson [19].)

All figures refer to the cobalt obtained by extraction with concentrated hydrochloric acid. The mean value (4·0 p.p.m.) in unhealthy soils is higher than that found by Kidson (<2 p.p.m.).

TABLE 2. *Cobalt-content of soils in Devonshire*

Unhealthy soils from Dartmoor.	Mean of 18 samples, 4·0 p.p.m. Co.
,, ,, ,, ,,	Range of values, 1·9–6·7 p.p.m. Co.
Healthy soils from Devon.	Mean of 12 samples, 19·6 p.p.m. Co.
,, ,, ,, ,,	Range of values, 13·0–32·8 p.p.m. Co.

Kidson [18] has pointed out that the cobalt-content of a wide variety of soils is related to the magnesium-content of their parent rocks, and some observations in south Devon appear to confirm this view. Table 3 shows the relative magnesium-contents of granite from Hay Tor Quarry (about one mile from Hedge Barton Farm) and of shales of palaeozoic age.

TABLE 3. *Magnesium-contents of Parent Rocks*

	Granite [20] *Hay Tor Quarry*	*Shale* [21] *Delabole*	*Shale* [21] *Bangor*	*Shale Marley*
	per cent.	per cent.	per cent.	per cent.
MgO . .	0·14	1·09	2·20	2·68

The cobalt-content of the Hay Tor sample of granite is given as 0·00 per cent. Presumably, the actual content is extremely small and the high content of the soil derived from granite is due to concentration by weathering. The shale from Marley contains 15 p.p.m. cobalt and the soil derived from it 26·0 p.p.m.

Attempts have been made [22] to correlate the cobalt-content of pastures with the frequency of incidence of sheep ailments. It was found that healthy pastures in the Nelson district of New Zealand contained, in general, a higher percentage of cobalt than the unhealthy pasture at Glenhope. The mean of 14 samples from healthy pastures is 0·31 p.p.m. and of 12 samples from unhealthy pastures is 0·20 p.p.m. Co. All figures are calculated on a dry-matter basis. The feeding of supplements of cobalt of the order of 8 mg.—0·4 mg. Co per week has been completely successful in overcoming bush-sickness at Glenhope and Morton Mains in New Zealand (15).

Attempts were made on Dartmoor, before the New Zealand papers were published, to increase the nutritive value of the herbage by giving dressings of slag at 10 cwt. per acre to the pastures. Groups of sheep were kept on slagged and unslagged pasture without effect. Both groups became badly affected in the late summer, particularly those on the slagged land, and it was necessary to shift the adult flock to a lowland pasture at Rattery in order to save it. The recovery was strikingly rapid. In less than ten days sheep which had had to be carried to the lorry to be brought to the change pasture were strong and very active.

In the autumn the lambs became weak and showed the characteristic symptoms.

It was decided that a preliminary trial with mineral supplements should be carried out with a view to making a large-scale experiment in the following year. Owing to the lack of grass a daily ration of cake was fed to the lambs, of which twenty-four were available for experimental purposes. These were divided into two groups, and the cake of one was sprayed with a solution of cobalt chloride and manganese and zinc sulphates in quantity to give 7 mg. Co, 14 mg. Mn, and 1·365 gm. Zn per lamb per week. The cake fed to the other group was sprayed with an equal volume of distilled water.

The mineral group recovered and increased in weight more rapidly than the control group at first, but at the end of two months both groups were of equal live-weight at the mature stage of 50 lb. The animals in the mineral group were, however, more healthy in appearance than those in the control group.

It was intended to follow up this preliminary work with a full trial, using supplements of cobalt and other minerals, singly and in combinations, but the work was being done on a commercial farm and became too expensive. The flock was sold off and no more work could be done.

The observations and facts here recorded are admittedly very incomplete, but are published for possible use by future workers who can command more ample resources.

Summary

1. The symptoms of a disease of sheep on Dartmoor are described, and their resemblance to those of 'pine' in Scotland and 'bush-sickness' in New Zealand is shown.

2. The climatic, topographical, and soil conditions of regions where these diseases are found are compared, and figures for the available iron and the cobalt in soils and pastures are given. It is shown that there is a possible connexion between the incidence of and recovery from the disease and the cobalt-content of soils.

3. The mineral-content of the herbage from sick and healthy areas appears to bear no direct relation to onset or recovery.

4. The rapid recovery of sheep when moved on to lowland pasture points to causes other than parasitic.

5. Preliminary trials with mineral supplements of cobalt, manganese, and zinc have given indications of the effectiveness of these elements in controlling the disease.

6. Owing to the enforced abandonment of this work the observations and results here recorded are offered to any worker who may be able to continue the investigation.

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THE ROTHAMSTED FIELD EXPERIMENTS ON BARLEY 1852–1937

A. THE OLDER ROTHAMSTED EXPERIMENTS

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IN 1845 Lawes and Gilbert started some field experiments on barley on an area of ten acres: other work, however, was so pressing that they had to discontinue after the first season. They began again in 1852: this time in Hoosfield on an area of 5 acres divided into nearly square plots of about $\frac{1}{5}$ acre each. The purpose, as with the Broadbalk experiments on wheat, was to test the relative merits of Liebig's and Lawes' and Gilbert's hypotheses as to crop requirements. According to Liebig's hypothesis, plants would make full growth if supplied with mineral manures, phosphates and the alkalis, potassium, sodium, and magnesium: if these were present in ample amount plants could obtain their nitrogen from the air. According to Lawes' and Gilbert's view they could not do this, but were entirely dependent on an adequate supply of nitrogen from the soil.

The plan of the experiment was somewhat like that of the Barnfield mangold experiment: four strips, receiving respectively complete minerals, no phosphate, no potash, and no minerals, were crossed by others receiving no nitrogen, sulphate of ammonia supplying 41 lb. nitrogen per acre,[1] sulphate of ammonia in double this amount,[1] and rape cake also equivalent to the double dressing. Other plots received respectively 14 tons of farmyard manure annually, '20 bushels clay and weed ashes', and nitrate of soda in dressings equivalent to the sulphate of ammonia. After the experiment had continued for six years the results were summarized and discussed in a paper [1] which is perhaps the best ever published by Lawes and Gilbert on barley-growing, and in it one finds the germs of most of the ideas they ever put out on the subject. The results, set out in Table 1, led to the following conclusions:

> Mineral manures alone, without any nitrogen, increased the yield of barley. Inorganic nitrogenous manures, however, even when used alone, had a much more striking effect, and gave larger increases than farmyard manure containing not only much more nitrogen but also mineral matter. Their action was, within limits, in accordance with the amount of nitrogen they supplied. The effect of the inorganic nitrogenous manure was enhanced by the addition of mineral manure.

[1] These amounts correspond to 41 and 82 lb. of nitrogen, the figures given in the 1857 and 1873 papers. In the 1893 summary, Gilbert prefers the figure 43 lb., which has been adhered to ever since. In accordance with the notation of those times the quantities were stated in terms of ammonia: 50 and 100 lb. respectively per acre.

The results accorded entirely with Lawes' and Gilbert's views as to the necessity for a supply of nitrogenous fertilizer to ensure plant-growth.

TABLE I. *Yield of Barley, Total Produce and Grain. Average of the Six Years 1852–7, in cwt. per acre*

	Total Produce					
	No nitrogen	*Nitrogen given as*			*Increment due to sulphate of ammonia*	
		Sulphate of ammonia		*Rape Cake*		
		41 lb. N	82 lb. N	82 lb. N	*1st dose*	*2nd dose*
No minerals . .	30·3	42·2	51·7	55·5	11·9	9·5
'Mixed alkalis' only*	30·6	45·1	51·4	52·6	14·5	6·3
Superphosphate[1] only	32·1	51·1	58.8	56·3	19.0	7·7
Superphosphate and 'mixed alkalis' .	35·1	52·3	61·4	56·2	17·2	9·1
Farmyard manure[2] .	46·4					
Nitrate of soda alone		41 lb. N 46·7†		82 lb. N 55·3†		

	Grain					
	No nitrogen	*Nitrogen given as*			*Increment due to sulphate of ammonia*	
		Sulphate of ammonia		*Rape cake*		
		41 lb. N	82 lb. N	82 lb. N	*1st dose*	*2nd dose*
No minerals . .	14·1	19·6	23·2	23·8	5·5	3·6
'Mixed alkalis' only*	14·5	20·3	21·8	22·4	5·8	1·5
Superphosphate only	15·6	22·7	24·8	23·9	7·1	2·1
Superphosphate and 'mixed alkalis' .	17·1	23·2	25·0	23·8	6·1	1·8
Farmyard manure .	21·5					
Nitrate of soda alone		41 lb. N 21·1†		82 lb. N 23·8†		

* 200 lb. sulphate of potash, 100 lb. sulphate of soda, 100 lb. sulphate of magnesia, per acre.

† 5 years only.

[1] 3½ cwt. per acre.

[2] 14 tons per acre.

Certain qualitative effects were noted. Nitrogenous manures gave larger leaves of darker green colour but the plants showed a greater tendency to lodge. Superphosphate caused earlier ripening, whilst the 'mixed alkalis' delayed ripening. Superphosphate increased the tendency to form grain, though not as much as had appeared in the early days of the crop, but it increased the proportion of total corn and of head corn. Sulphate of ammonia gave a higher proportion of corn to straw than nitrate of soda, though less yield. Both for sulphate of ammonia and nitrate of soda the second increment was less beneficial than the first.

All these conclusions passed into the general body of scientific knowledge and have become part of the text-book teaching on the subject.

The nitrogen in the grain and the straw was determined and several deductions were drawn from the figures obtained. In discussing the relations between quality and chemical composition of grain, three conclusions were drawn:

1. The percentage of nitrogen in the grain varies with the supply of nitrogen in the manure; the extent of variation, however, is not very great.
2. High maturation, which they regarded as identical with high quality, is associated generally with low percentage of nitrogen.
3. The quality is, on the average, better with small than with large crops.

These conclusions have formed the subject of a great deal of subsequent work extending over many years: the first two are well founded, the third is not.

Another important inquiry, begun in this paper and followed up later, was concerned with the fate of the nitrogen supplied in the manure. Only about 40 per cent. was taken by the crop; the results are given in Table 2.

TABLE 2. *Recovery of Nitrogen by the Barley Crop: Average, lb. per acre per annum*

From soil alone (unmanured crop): 28·4 lb.
From nitrogenous manures:

	Supplied in fertilizer	*Additional nitrogen taken by crop*	*Percentage recovered*	
		1857 values	*1857 values*	*1873 values*
Sulphate of ammonia .	41	16·3	40	48
	82	33·6	41	..
Nitrate of soda . .	41	15·2	37	..
	82	33·3	41	..
Rape cake: 1852–7 . .	95*	27·6	34	36
Farmyard manure . .	..	..	..	10·7

* The figure varied from 82 to 100 lb.; from 1858 onwards the dressing of rape cake was 1000 lb. per acre, supplying about 50 lb. of nitrogen.

Where, they ask, has the remaining 60 per cent. gone to?

It was characteristic of Lawes and Gilbert that fourteen years elapsed before they published another paper [2] on barley, although the experiments continued uninterruptedly. By that time they had thought a good deal about the various aspects of this question of loss of nitrogen, which they considered might take place in four ways:

1. by drainage;
2. by volatilization of ammonia;
3. by evolution from the plant;
4. by fixation in some unavailable form in the soil.

A. Voelcker's analyses of the Broadbalk drainage waters, and their own investigations in connexion with the Rugby sewage experiments, satisfied them that drainage accounted for most if not all of the loss. No analyses of the soil were at that time done.

Although no reference is made to the fact in this paper, a few samples of soil had in fact been taken in 1868, and these showed no accumulation of nitrogen on the plots receiving sulphate of ammonia or nitrate of soda. Full sampling did not begin till 1882.

Comparison with the data for Broadbalk wheat brought out the interesting result that both crops yield somewhat similar weights per acre of total produce on the unmanured plots and on those receiving farmyard manure, but they make different use of the material, barley converting more of it into grain than wheat does.[1] Artificial manures gave a larger growth of barley than of wheat, though this could be explained by a difference in the mode of application.

TABLE 3. *Comparison of Yields of Wheat and Barley, Average of 20 years, 1852–71*

	Unmanured		*Farmyard manure*		*Complete artificials*	
	Wheat	*Barley*	*Wheat*	*Barley*	*Wheat (Plot 6)*	*Barley (Plot 4A)*
Average annual yield: total produce, cwt. per acre	21·1	22·7	54·1	53·0	39·4	51·9
Nitrogen recovered, per cent.	..	..	14·6	10·7	32·4	48·1
Grain, percentage of total produce	38·6	46·7	37·3	46·6	37·7	45·2
Grain, cwt. per acre	8·15	10·6	20·2	24·7	14·9	23·5

This similarity in yield of total produce is observed also at Woburn [3], where also the barley converts more of its substance into grain than does wheat. In view of the wide differences in time of sowing, this result deserves fuller study.

There had been some change in the design of the experiment in 1864, when sodium silicate was included in the fertilizers, and again in 1868 when nitrate of soda was substituted for what had during the first five years been the double dose of sulphate of ammonia, but for the next ten years was a single dose only. Since 1868 there has been no further change. The silicate produced a marked effect on the plots receiving no phosphate; indeed the silicate was at first suspected to contain phosphate, but this was shown not to be so. Lawes and Gilbert concluded that it possibly renders available some of the phosphorus locked up in the soil. Hall and Morison [4] subsequently concluded that the seat of action was in the plant, not in the soil, the silicate facilitating the uptake of phosphate, but R. A. Fisher [5], emphasizing the higher total-phosphorus content of the crop manured with silicate, reverted to Lawes' and

[1] In discussing this similarity of yield of total produce of wheat and of barley Lawes and Gilbert expressed the view that the wheat would ultimately maintain a higher total produce than the barley, which has actually happened.

Gilbert's view that the silicate had somehow increased the availability of the soil phosphorus. The problem is one for the soil chemist (Table 4).

Two new problems were raised by Lawes and Gilbert in this second barley paper. The influence of season on the yield and composition of the crop was studied by comparing the 'best' with the 'worst' season. This was done with much shrewdness, but the method is extremely

TABLE 4. *Effect of Sodium Silicate. Hoosfield Barley*
Ten-year Averages from 1868 to 1937

Dressed Grain, bushels per acre

	No minerals		*Superphosphate*		*Alkali salts*		*Complete minerals*	
	No silicate	*Silicate**	*No silicate*	*Silicate*	*No silicate*	*Silicate*	*No silicate*	*Silicate*
Plot No.	*1AA*	*1AAS*	*2AA*	*2AAS*	*3AA*	*3AAS*	*4AA*	*4AAS*
1868–77	30·8	36·5	44·4	45·8	31·4	40·6	44·4	47·6
1878–87	27·9	34·7	41·0	43·1	29·7	36·3	40·8	44·5
1888–97	24·1	31·3	41·2	43·2	25·7	33·5	38·5	42·5
1898–1907	22·5	30·1	37·6	37·0	23·4	30·4	36·4	39·3
1908–17	25·4†	29·8†	37·4†	38·3†	24·6†	30·0†	38·4†	38·7†
1918–27	16·7	20·9	33·7	33·7	13·6	18·4	30·2	29·6
1928–37	15·7‡	23·7‡	38·2‡	37·4‡	19·9‡	25·0‡	35·5‡	38·4‡
Mean	23·3	29·6	39·1	39·8	24·0	30·6	37·7	40·1

Total Grain as percentage of Total Produce

1868–77	46	48	47	47	45	46	47	45
1878–87	46	47	48	47	46	48	46	45
1888–97	45	45	46	46	44	44	44	44
1898–1907	44	46	44	44	43	44	43	45
1908–17	45†	46†	46†	45†	45†	45†	45†	45†
1918–27	42	45	48	48	35	39	45	44
1928–37	36‡	42‡	46‡	46‡	40‡	40‡	44‡	45‡
Mean	43	46	46	46	43	44	45	45

* Sodium silicate was applied at 400 lb. per acre. All plots had nitrate of soda.
† 9 years only. ‡ 8 years only.

limited in its application because it involves such a large element of selection; it is therefore unnecessary to record their various deductions. But it remained the only method in use at Rothamsted for many years until finally it was displaced by modern statistical methods.

The other problem related to the fall in yield which was already setting in on the unmanured and on the incompletely manured plots, though not yet on the plots receiving farmyard manure or complete artificials. Here again the method of study consisted in direct comparison of one year with another, no method of detailed examination being available.

Little more was added in the summary of the Fifty Years of Experiments published in 1895 [6]: analyses of ash were recorded: these will be dealt with later; and there was some discussion of the changes in composition of the soil.

A. D. Hall summarized the whole of Lawes' and Gilbert's work in 1905, soon after he went to Rothamsted. He continued the discussion of the effects of season, comparing a 'typical wet' year with a 'typical dry'

one, and although this was done with much restraint and judgement the method has the same defects as that of Lawes and Gilbert.

B. THE MODERN ROTHAMSTED EXPERIMENTS

Whilst the classical Hoosfield experiments are continued, several new series of experiments have been started, the most extensive being those done in association with the Institute of Brewing, to study *inter alia* the influence of soil, season, and manuring on the yield and malting quality of barley. These experiments were done not only at Rothamsted and Woburn but also on a number of farms where good malting barley is grown: the scheme was the same at each centre, and the same stock of seed was used in all the experiments: the results are therefore strictly comparable.

Ratio of grain to total produce. The true measure of crop growth is the total amount of dry matter formed: the division of the dry matter between leaf and grain or leaf and root or tuber is a different process. The total dry matter has only recently been determined at Rothamsted as a regular part of the routine, but the total produce, which includes about 14 per cent. of water, is known from the outset.

There is considerable uniformity about the ratios of grain to total produce. Whatever the variety, the manuring, or the yield (excepting when this is very low) the barley plant put about 46 per cent. of its total produce into grain for the first 70 years of the experiment, but later the proportion fell to about 40. The figures at Woburn are practically the same: 45 per cent. at the beginning and 40 per cent. towards the end of the period. The data for rotation barley are fewer, but a usual result is about 45 to 48 per cent. Even fallowing has but little effect on the ratio. (Table 5).

TABLE 5. *Grain per 100 parts of Total Produce*

(A) Barley grown continuously. Hoosfield, Rothamsted. Ten-year averages

Years	Variety	*Unmanured*	*Complete minerals*	*Sulphate of ammonia*	*Nitrate of soda*	*Sulphate of ammonia and minerals*	*Nitrate of soda and minerals*	*Farmyard manure*
Plot Number		*1–0*	*4–0*	*1A*	*1AA*	*4A*	*4AA*	*7–2*
1852–61	1852–80 Chevalier	46	49	46	..	44	..	43
1862–71	1852–80 Chevalier	46	49	48	44*	46	46*	50
1872–81	1852–80 Chevalier	50	51	49	48	47	47	46
1882–91	1881–90 Archer's Stiff Straw	47	50	47	46	46	45	45
1892–1901	1891–97 Carter's Paris Prize	..	..	..	..	..	..	..
	1898–1901 Archer's Stiff Straw	44	45	44	44	46	44	43
1902–11	1902–5 Chevalier	46	40	45	44	44	43	43
1913–17†	1906–16 Archer's Stiff Straw	51	47	51	47	48	47	45
1918–22	1917–18 Plumage	51	49	50	46	52	50	47
1923–32	1919–37 Plumage Archer	39	36	39	37	44	42	40
1934–7†	1919–37 Plumage Archer	38	43	37	36	46	44	39
Mean 1852–1937		45·8	46·1	46·2	..	45·9	..	44·2
,, 1868–1937		45·4	45·0	45·9	44·0	46·1	45·1	43·6
Woburn		42·0	44·0	41·0	41·0	40·0	42·0	44·0

* 1868–71. † 1912 and 1933 fallow.

TABLE. 5 (*cont.*)

(B) Barley grown in rotation

	Rothamsted 1922–37	*Woburn* 1922–37	*Wellingore* 1929–34	*Wye* 1931–7	*Sparsholt* 1930–2
Mean	44·9	38·2	48·0	47·8	46·0
Range	35–50	32–49	45–52	44–53	38–51

Six-course Rotation Experiments. Mean of 8 years, 1930–7

Nitrogen series	Units of fertilizer	0	1	2	3	4
	Rothamsted	45	44	44	44	43
	Woburn	33	37	39	39	38
Phosphate series	Units of fertilizer	0	1	2	3	4
	Rothamsted	44	43	44	43	44
	Woburn	38	40	39	39	39
Potash series	Units of fertilizer	0	1	2	3	4
	Rothamsted	45	45	44	44	43
	Woburn	38	40	40	37	38

1 unit of nitrogen = 0·15 cwt. N per acre as sulphate of ammonia
1 unit of phosphate = 0·15 cwt. P_2O_5 per acre as superphosphate
1 unit of potash = 0·25 cwt. K_2O per acre as muriate of potash

Yield of Total Produce, lb. per acre

Plots	*Unmanured*	*Complete minerals*	*Sulphate of ammonia*	*Nitrate of soda*	*Sulphate of ammonia and minerals*	*Nitrate of soda and minerals*	*Farmyard manure*
Years							
1852–61	2782	3517	4119	..	5827	..	5908
1862–71	2126	2807	3719	4047*	5808	5900*	5958
1872–81	1542	1936	2998	3318	4968	5157	6253
1882–91	1454	1858	2844	3415	4854	4998	5940
1892–1901	1325	1640	2210	2946	4378	4701	5913
1902–11	1276	2338	2651	3216	5087	5162	6184
1913–17†	1689	3000	2947	3433	4635	4781	5052
1918–22	1136	1975	1811	2212	3450	3781	3906
1923–32	1013	1992	1580	2170	3504	3580	4423
1934–7†	2248	4482	2813	3672	5959	6088	8030
Mean 1852–1937	1646	2424	2813	..	4877	..	5747
,, 1868–1937	1429	2209	2525	3085	4616	4805	5701

* 1868–71. † 1912 and 1933 fallow.

We can offer no explanation of the fall in the ratio after a long period of years: it is apparently a deterioration phenomenon and it is not shown on the fully manured plot 4 A. But it is not related to the yield, for the yields in 1934–7 were among the highest of the whole period, but the ratios were among the lowest. And, strangely enough, it appears on the farmyard-manure plot. Weeds may account for some of the fall but not for much.[1] Although the effect of manures is very small it can be detected, and it is similar at Rothamsted and at Woburn. For the first fifty years mineral manures without nitrogen give the highest ratios. Sulphate of ammonia gives rather lower ratios and nitrate of soda slightly lower still, farmyard manure lowest of all: i.e. nitrogenous manures tend

[1] The Wellingore experimental barley, 1931, was very weedy; its yield was measured

to increase the straw slightly more than the grain. In the later years when deterioration has set in the ratios on the incompletely manured plots fall more than on those receiving complete manure.

The effect of variety is not very pronounced. Carters' Paris Prize gave somewhat lower ratios, as well as lower yields, than Archers' Stiff Straw, and Plumage Archer during its first years gave both higher ratios and higher yields. But this effect soon passed, and in later years the ratios fell off, though the yields rose. In consequence of this close relation between total produce and yield of grain it is not necessary to give both sets of data, and we shall therefore confine ourselves to the results for grain.

Factors Influencing the Yield of Barley

1. *Soil Type and General Environmental Conditions.*

The average yields of the Institute of Brewing series are given in Table 6. They range from 9·5 to 40 cwt. of grain per acre and they fall into four well-defined groups.

TABLE 6. *Results of the Modern Series of Barley Experiments*
(*Institute of Brewing Series*)

	Place	*Soil*	*Mean yield 1922–31 Fully manured (cwt. per acre)*	*Highest recorded yield in period 1922–31 (cwt. per acre)*
I.	Dunbar	Medium loam	40	44·5
II.	Longniddry	Medium loam	30	30·5
	Walcott	Fen	27	30
	Eyton	Light loam fairly moist	25	27
	Wye	Loam	23	27
	Wellingore	Light loam	23	30
	Rothamsted	Heavy loam	19	25
	Woburn	Light loam	18	29
III.	Newport (Salop)	Sandy loam fairly moist	18·5	21
	Cawkwell	Medium loam	18·5	21
	Chiselborough	Light loam	17	21·5
IV.	Martlesham	Light sand	9·5	12·5

by weighing total produce, and by taking grab samples from the swathe for the estimation of grain-straw ratios. The weights of the samples in kilos, air-dry, were:

Total Produce	*Weeds*	*Grain*	*Straw*
53·1	0·62	24·5	28·0

Weeds as per cent. of straw = 2·21.
Percentage ratio of grain to total produce:
With weeds included as straw 46·1. Without weeds 46·6.

Even in this weedy crop, the weight of weeds had only a very small effect on the ratio of grain to total produce. To shift the percentage ratio from 46 to 40 the weight of weeds would have to be about 22 per cent. of the weight of straw at threshing time, or (allowing for the high moisture-content of fresh weeds as compared with straw) nearly equal to the weight of the straw at harvest. It is clear, therefore, that the fall in the ratios of grain to total produce in recent years on Hoosfield cannot be due entirely to increased weed-infestation.

It is remarkable that the soils within these groups should show such similar maximum yields. The second group is the most extensive and includes a number of soils which would be classed as of medium fertility: the average yields during the period range from 18 to 30 cwt. per acre, but the maximum recorded is always about 30, and neither at Rothamsted nor at Woburn has this ever been much exceeded. At Rothamsted the highest record is 35 cwt. per acre, attained on Hoosfield in 1934 and again in 1935; values between this and 30 cwt. have been obtained on four other occasions since the experiments began in 1852: three other times on Hoosfield, viz. 1854, 1857, and 1913, and once in the Agdell field rotation barley, in 1861. At Woburn the 30 cwt. was just exceeded on two occasions since 1876, viz. in 1882 and 1885, and it was almost reached on four other occasions: in 1883, 1892, 1899, and 1907. These results suggest a limit which can in favourable conditions be attained, but which we have not yet succeeded in passing. The limit is obviously set by the environmental conditions, presumably by the air and water relationships of the soil, rather than the supplies of nutrients, for no amount of plant food will raise the yields of Group II to the level of Group I.

The limit for these soils of medium fertility is, however, considerably above their average yield, and the problem arises whether we can hope to raise the average to the limit. Apart from waiting for the very favourable season, the only two ways in which we have as yet succeeded in reaching the limit have been by a preceding fallow, or by giving a large dressing of nitrogenous manure (p. 285). Variations in method of cultivation have had surprisingly little effect (see *Rothamsted Ann. Rept.*, 1926, pp. 34–45), and no other method has yet done much to raise the yield considerably.

It is not possible to say how much of the difference between centres is due to soil and situation, and how much to climatic factors, because of their close interrelation. The Rothamsted and Woburn results provide a comparison of soil types to some extent independent of climate. This comparison will be made at the various stages of the following discussion.

2. *Variation in Yield in Different Seasons.*

Seasonal variation independent of soil differences is more readily studied in experiments such as those in Hoosfield, Rothamsted, and Stackyard, Woburn, where barley has been grown continuously on the same land for a long period of years. Continuous cropping, however, introduces a complication, in that it leads to slow changes in fertility, the effect of which must be eliminated from the results, before the effects of weather factors can be estimated.

An investigation has been made for the Rothamsted data by Miss W. A. Mackenzie [7], and for the Woburn data by Miss A. M. Webster [3]. The method, developed originally by R. A. Fisher [8] for his study of the Broadbalk wheat yields, consists in fitting smooth curves (fifth order polynomials) to the yield data over the period of years under examination. These curves measure the steady changes in yield due to

factors acting over long periods of time. Deviations from the smooth curves may be ascribed to factors whose intensity varies irregularly from year to year, of which climatic factors, acting directly on the plant or indirectly through the soil, are the most important. Correlation of these deviations with individual weather factors enables their effect to be measured, and the particular factor which has been most intensively studied is rainfall (p. 280). The variation represented by the deviations from the smooth curves is referred to as 'annual variation'.

Of the long-term changes measured by the smooth curves, the steady diminution of yield represented by the linear term can undoubtedly be ascribed to soil deterioration (p. 279). The variations represented by the higher order terms are usually described as 'slow changes'. Their causes are less easily explained. Part of the variation represented by the second order term, probably a considerable part in the Rothamsted data, is also attributable to soil deterioration, since this would be expected to proceed more slowly as the level of yield falls. Other possible causes are changes in infestation by weeds, in management, or in the variety of the crop sown, and systematic fluctuations in climatic factors (weather cycles).

The proportions of the total variation accounted for by deterioration, slow changes, and annual variation are shown in Fig. 1, where the variation is expressed as the relative variance ($\frac{100 \times \text{actual variance}}{(\text{mean})^2}$). The relative variance and the fractions of it attributable to deterioration and annual variation are least for the plots receiving farmyard manure and complete artificials, and greater on the incompletely manured and unmanured plots. The sulphate of ammonia plots at Woburn are exceptional in showing a very high relative variance, and this is due to the very large variation ascribable to deterioration, caused by exhaustion of the lime and the development of acidity. On comparable plots the relative variance is slightly greater for the sandy soil of Woburn than for the heavy soil at Rothamsted, except where minerals only were applied, and this is also true in most cases of the deterioration and annual variation components. This difference would probably be accentuated if the Woburn experiments had continued for as long a period as the Rothamsted experiments. This is illustrated by Fig. 2, in which the yields on the unmanured and fully manured plots are plotted against time. The average yields at Rothamsted and Woburn are about the same, as also are the peak values, but at Woburn the yields varied more from year to year and fell off more rapidly than at Rothamsted.

The mean yields and the variability as measured by the standard errors calculated before and after elimination of the variance due to deterioration and slow changes are given in Table 7.

The standard errors give information similar to that provided by the relative variance (Fig. 1), but expressed instead on an absolute scale. The variability of the yields of the differently treated plots from season to season is more uniform than their mean yields. Thus the variability (standard error), including all causes of variations, for the Rothamsted plots ranges only from 6·4 to 10·1 bushels, whilst the mean yield ranges

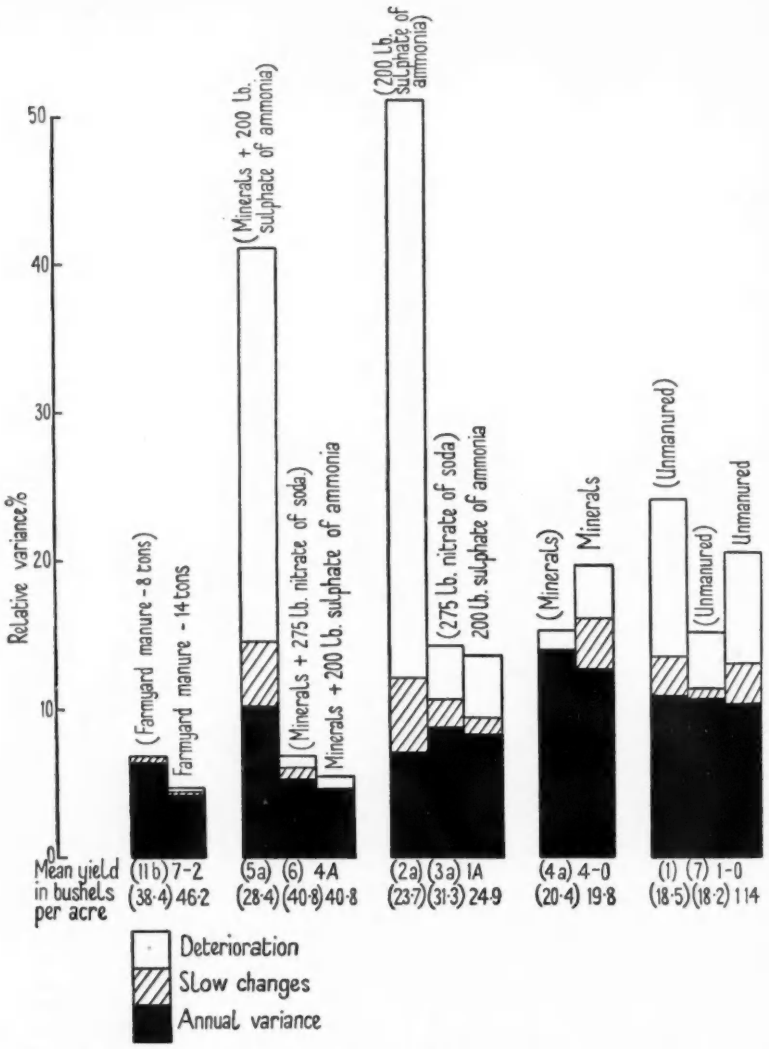

FIG. 1. Comparison of causes of variation of yield of grain on Hoosfield, Rothamsted (70 years, 1852–1921), and Stackyard Field, Woburn (30 years, 1877–1906). The figures and descriptions relating to Woburn are given in brackets.

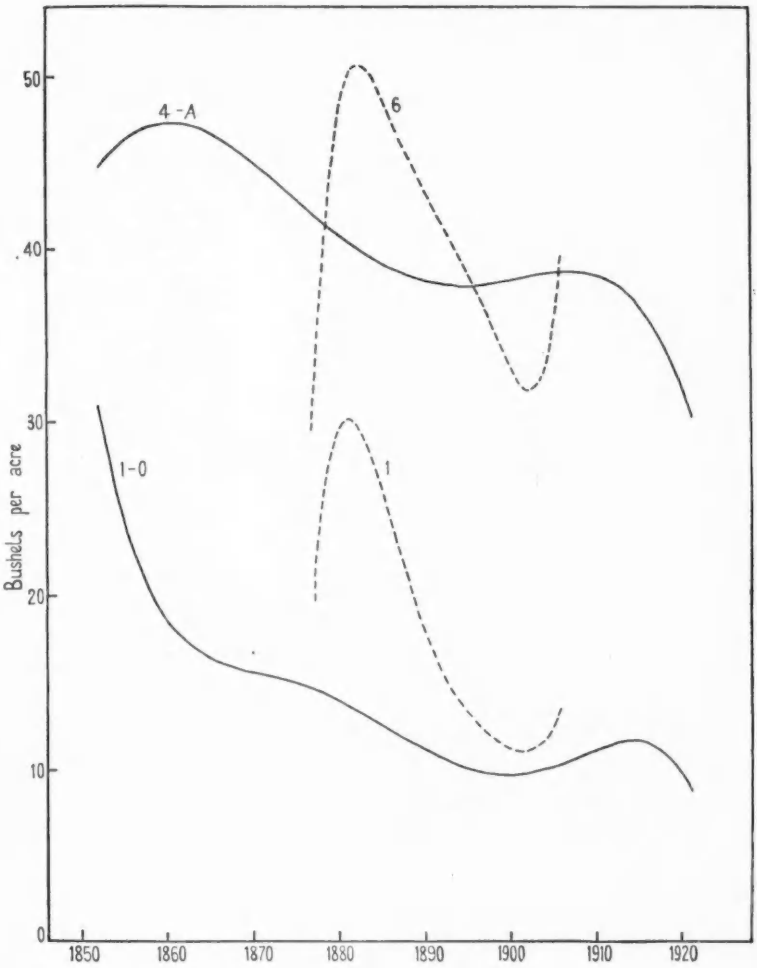

FIG. 2. Smooth curves fitted to the yield of grain in bushels per acre.

Full lines: Hoosfield, Rothamsted. Plot 1–0, unmanured. Plot 4–A, complete artificials (N as sulphate of ammonia).

Dotted lines: Stackyard Field, Woburn. Plot 1, unmanured. Plot 6, complete artificials (N as nitrate of soda).

from 14 to 46 bushels. Similarly at Woburn, excluding the sulphate of ammonia plots where the variation was very high because of the development of acidity, the range of the standard error is 7·1 to 11·8 bushels, and of mean yield, 18·3 to 38·4 bushels.

It is remarkable that the variability values for corresponding plots at Rothamsted and Woburn are very similar in magnitude. The annual variation, after elimination of deterioration and slow changes, is usually rather greater at Woburn than at Rothamsted, as was shown from the consideration of the relative variances.

TABLE 7. *Mean Yield and Variability (standard errors)*

	Rothamsted (1852–1921)				*Woburn (1877–1906)*			
Treatment	*Plot*	*Mean yield (bushels per acre)*	*Standard error*		*Plot*	*Mean yield (bushels per acre)*	*Standard error*	
			*Total variation**	*Annual variation†*			*Total variation**	*Annual variation†*
Unmanured	1–0	14·0	± 6·35	±4·34	1	18·5	± 9·1	±6·4
,,	6–1	15·5	± 7·08	±4·62	7	18·3	± 7·1	±6·0
Complete minerals, no nitrogen	4–0	19·8	± 8·84	±6·80	4	20·4	± 8·0	±7·8
Complete minerals + nitrate of soda	4–AA‡	39·3	± 8·97	..§	6	40·8	±10·7	±9·4
Nitrate of soda only	1–AA‡	25·5	± 8·38	..§	3A	31·3	±11·8	±9·3
Complete minerals + sulphate of ammonia	4–A	40·8	± 9·56	±8·61	5A	28·4	±18·2	±9·1
Sulphate of ammonia only	1–A	24·9	± 9·18	±6·90	2A	23·7	±17·0	±6·3
Farmyard manure	7–2	46·2	±10·06	±9·14	11B	38·4	±10·1	±9·7

Note: The rates of application of nitrate of soda and sulphate of ammonia differed slightly (43 lb. N at Rothamsted, 41 lb. N at Woburn). The rates of application of farmyard manure also differed (14 tons per acre at Rothamsted; about 8 tons per acre at Woburn: see Table 12 p. 286).

* S.E. for a single year.

† S.E. for a single year after eliminating effects of deterioration and slow changes.

‡ For the period 1868–1921. § Not yet determined.

3. *Effect of Climatic Factors on Yield.*

Rainfall.—The rainfall data at Rothamsted are much more complete than those for radiation, hours of sunshine, or temperature, and in consequence fuller studies have been made of rainfall effects than of any others.

The effect of the rainfall on the yields in Hoosfield, Rothamsted, was examined by J. Wishart and W. A. Mackenzie [9], and on the Woburn data by Miss A. M. Webster [3], using the method devised by R. A. Fisher for the Broadbalk wheat data.[1] The rainfall effects are expressed as linear regressions of yield on rainfall, and the results are presented in the form of curves showing the average benefit or loss caused by an additional inch of rain over the average, at any time during the year.

Miss Webster found that none of the rainfall regression functions derived from either the Rothamsted or Woburn data were statistically significant. For the Rothamsted data, it was found possible to divide the plots into groups of similar manurial treatment, such that within a group the relation to rainfall was similar, but between groups the relation

[1] The simple correlation method previously used by Hooker is unsuited to the Hoosfield data because of the need for eliminating the effect of the steady fall in yield.

differed. It is probable that the differences between groups indicates a real dependence of the rainfall effect on manurial treatment, for though the rainfall regressions for individual plots are not significant, many sources of variation are eliminated if differences between plots are considered.

Comparing plots within a group, Cochran [10] found for the Broadbalk wheat and the Woburn barley data that the similarity of seasonal variation remained after the elimination of rainfall effects, i.e. within a group the deviations from the regressions on rainfall were correlated. This is probably also true of the Hoosfield barley data, though these have not yet been examined. The result indicates that weather conditions, as yet undiscovered, influence in a similar way the yields on all the plots of a group. The failure to detect them is partly attributable to the inadequacy of the present measurements to express the meteorological conditions that control the growth of crops. Also, the relation between yield and the weather factors examined is probably more complex than the linear relation assumed for the purpose of the statistical examination: this seems to be true for the Woburn data. Finally, it is assumed that the effect of a weather factor depends only on its intensity at the time of action, and is independent of its intensity and of the intensity of other factors during the preceding growth of the crop. This assumption probably is unjustified. Rain falling after a long spell of drought probably affects growth far more than the same amount of rain falling after a wet period.

Wishart and Mackenzie's results indicate in general that the mean rainfall at Rothamsted[1] is for most of the year too high for optimum yield of the barley crop, and the yield tends to be lower after wet Octobers and springs than after dry ones. Additional rainfall about March and April seems to be distinctly harmful, and there is no sign of harmful effects from drought during this period. On the other hand, summer rainfall, especially in July, is beneficial[2] (Table 8).

These relations seem to be fairly general over the large eastern block of England in which Rothamsted is situated: they agree fairly well with the results of Hooker's survey of the averages for the eastern counties, except that the periods are not quite the same: he found that additional

[1] The mean rainfalls at Rothamsted and Woburn are, in inches:

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
Rotham-sted .	2·41	2·03	1·97	2·05	2·07	2·21	2·74	2·66	2·38	3·14	2·88	2·87	29·41
Woburn	1·64	1·45	1·69	1·43	1·90	1·94	2·18	2·25	1·75	2·64	2·23	2·33	23·43

The Rothamsted data are the means for 61 harvest years 1870 to 1930–31, the Woburn data are the means for the years 1881–1915. There is no evidence that the total rainfall at Rothamsted is changing, but there is a tendency for an altered distribution: there is now usually less in spring and autumn, but more in summer and winter than formerly, so that the Rothamsted climate is presumably becoming better adapted for barley than it was.

[2] As an example of the good fortune that attended Lawes' and Gilbert's use of defective methods, it is interesting to note that in their two contrasted years, the bad one, 1856, had a wet spring, and the good year, 1854, had a dry spring and moist summer.

rainfall was more harmful during the period mid-December to the end of February than later on, and there was a slight beneficial effect of additional rainfall in summer (May to early July): he himself did not regard this as significant but Wishart and Mackenzie think it is. At Woburn also additional rainfall in March and April appears to be harmful, though here the actual average appears to be approximately optimal, for drought is also harmful. The summer effect, however, is not seen: there is no evidence that additional rainfall then is beneficial.

TABLE 8. *Effect of One Inch of Rain above the Normal in each Month in Raising (+) or Lowering (−) the Yield of Barley (Hoosfield Rothamsted). Wishart and Mackenzie*

	Preceding autumn. Minimum benefit or maximum harm			*Preceding winter. Maximum benefit or minimum harm*			*Spring Maximum harm*			*Summer Maximum benefit*		
Plot	*Month*	*Bushels per acre*	*Percent. of average yield*	*Month*	*Bushels per acre*	*Percent. of average yield*	*Month*	*Bushels per acre*	*Percent. of average yield*	*Month*	*Bushels per acre*	*Percent. of average yield*
7–2	Beneficial Sept., Oct.						Feb.	−1·40	−3·0	July	+0·50	+1·1
4–A	Oct.	−0·10	−0·2	Nov.	0·00	0·0	Mar.	−0·90	−2·2	July	+0·30	+0·7
4–0	Oct.	−0·40	−2·0	Dec.	−0·35	−1·8	Apr.	−0·55	−2·8	July	+0·15	+0·8
3–A	Oct.	+0·10	+0·4	Dec.	+0·55	+2·0	Apr.	−1·30	−4·8	July	+0·30	+1·1
2–A	..	..	..	Oct.	−0·20	−0·5	Feb.	−0·95	−2·6	July	+0·15	+0·4
1–A	Oct.	+0·10	+0·4	Dec.	+0·25	+1·0	Apr.	−0·75	−3·0	July	+0·45	+1·8
1–0	Oct.	−0·40	−2·8	Dec.	−0·35	−2·5	Apr.	−0·70	−5·0	Aug.	+0·20	+1·4

Temperature.—Barley is very tolerant of wide ranges of temperature: indeed it is an important crop over most of Europe and Asia Minor, almost from sub-arctic to sub-tropical latitudes.

Statistical examination has failed to reveal any marked relationship between yields of barley at Rothamsted and Woburn and deviations from the mean temperature in the various months of the year. These mean temperatures (°C.) are:

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Rothamsted* .	3·1	3·6	5·1	7·4	11·1	13·9	15·8	15·4	13·2	9·2	5·7	3·6
Woburn† .	3·4	3·7	5·1	7·7	11·3	14·3	16·4	15·9	13·3	9·5	5·8	4·0

* 54 years, 1878–1931. † 22 years, 1896–1917.

Since barley neither gains nor loses by the normal deviations from these mean temperatures we may assume that they are satisfactory for good growth.

In earlier investigations of barley yields in the eastern counties, Hooker [11] concluded that the May and June temperatures and to a less extent the July and August temperatures in that region were already on the rather high side, and any excess of temperature was likely to be harmful. For May and June the Woburn results are similar though not pronounced.

Sunshine.—Variations in hours of sunshine cause little difference in yield of barley at Rothamsted. F. G. Gregory [12] has investigated this in pot culture and finds two sets of factors in operation: extra hours of

sunshine somewhat increase the rate of assimilation per unit area of leaf, but decreased numbers of hours (i.e. lessened radiation) cause an increase in leaf area. The two factors so nearly counterbalance that normal variations in hours of sunshine produce but little effect.

THE EFFECT OF FERTILIZERS ON YIELD

Nitrogenous Fertilizers

The nitrogenous fertilizers are the most consistent of all in their action on barley. In the Institute of Brewing series the increase given by sulphate of ammonia is remarkably uniform for a wide range of soils (Table 9).

Table 9. *Average Increases given by Fertilizers (cwt. per acre)*

	Sulphate of ammonia (1 cwt. per acre)	*Superphosphate (3 cwt. per acre)*	*Sulphate of potash (1 cwt. per acre)*
1st series (1922–5)	2·55	0·45	Nil
2nd series* (1928–32)	2·7	0·4†	0·03
		1·15‡	..

* Omitting Woburn, 1928–9. † Without sulphate of potash.
‡ With sulphate of potash.

Effect of 23·5 lb. Nitrogen (1 cwt. Sulphate of Ammonia per acre) on Yield of Barley Grain (cwt. per acre)

	Heavy loam	*Loam*	*Chalk loam*	*Sand*	*Fen*
Increased yield .	2·65	2·85	2·85	2·3	1·3
Mean yield .	16·25	19·8	22·55	13·35	26·25

Even individual farms do not vary much over a sufficient range of seasons: thus Rothamsted, Woburn, and Wellingore all give similar average returns in spite of the wide differences in soil type (Table 10).

Table 10. *Increase in Yield of Barley Grain (cwt. per acre) given by Sulphate of Ammonia in presence of Potassic and Phosphatic Fertilizers*

		I. *Rotation: ordinary conditions of practice* 1 cwt. sulphate of ammonia (23·5 lb. N) per acre*			II. *Continuous barley-growing 200 lb. ammonium salts (41 lb. N per acre)*		
		Mean increase 1922–31. Grain, cwt. per acre	*Increase for 1 part of N added*		*Mean increase before deterioration set in. Grain, cwt. per acre*	*Increase for 1 part of N added*	
	Soil type		*Grain*	*Total produce*		*Grain*	*Total produce*
Rothamsted	Heavy clay with flints . .	2·85	13·6	35	10·3†	28	67
Woburn	Sand, no lime present	2·8	13·3	..	10·7‡	29	73
Wellingore	Thin oolite limestone soil	2·6	12·4	..	..	..	..

* The details of yield are given in a series of Reports published in the *J. Inst. Brewing* during the years 1923 to 1928, also in the Rothamsted Annual Reports.
† First 20 years, 1852–71 (Series 2 and 4).
‡ First 15 years, 1877–91 (Nitrate of Soda series).

An entirely independent series of experiments made at Jealott's Hill [13] gave results similar to those for the rotations, as also did the numerous Continental experiments (averages of many hundreds) recorded by E. M. Crowther [14]: the increases per cwt. sulphate of ammonia are:

	Mean increase (cwt. per acre)	*Increase for 1 part of Nitrogen added*	
		Grain	*Total produce*
Jealott's Hill — Grain	3·3	15·7	38·6
Jealott's Hill — Straw	4·8	..	..
East Prussia	..	13	..
Jutland	..	13	35
Zealand	..	13	35

There is obviously no rigid rule, but it appears to be generally true that when barley is grown in rotation a dressing of the order of 1 cwt. sulphate of ammonia per acre (23·5 lb. of nitrogen) gives, over a wide range of soil types, an average increase of 13 or 14 lb. of grain and 35 to 40 lb. of total produce per lb. of nitrogen supplied.

Strikingly different results are obtained when barley is grown continuously. Figures are available for only two centres, Rothamsted and Woburn; they are, as for the rotation series, very similar at the two centres, but they are about twice as high as those obtained in the rotation experiments: 1 lb. of nitrogen gives an additional 28 or 29 lb. of grain and about 70 lb. of total produce (Table 10).

The simplest explanation of this difference in effectiveness is that the nitrogen status of the soil is much higher in rotations where clover is grown once in four or five years and farmyard manure is also added, than in the continuous series where neither farmyard manure nor clover is used.

This reduction in efficiency with increasing quantities of added nitrogen was shown in the first experiments made in Hoosfield (Table 1).

It is better studied in an experiment started in 1930 both at Rothamsted and Woburn on identical lines (Table 11). The crops are grown in rotation and five levels of manuring (artificials only, no farmyard manure) are given, but treatments are rotated so as to avoid cumulative effects.

In spite of the absence of farmyard manure the yield without added nitrogen at Rothamsted is very high, showing a high nitrogen status of the soil, so that the added nitrogen has much less chance of acting than at Woburn where the yield without added nitrogen is only 15·9 cwt. grain per acre. At both centres the increment of grain and of straw for the first dose exceeds the average of all doses, whilst at Rothamsted the largest dressing raises the yield of grain nearly to the limit.

In consequence of the high nitrogen status of the soil at Rothamsted the increases per lb. of nitrogen for the single dressing have been less than usual.

At Woburn where the nitrogen status was much lower, the results have been more like those from the continuous than from the rotation series, attributable perhaps to the absence of farmyard manure.

Recovery of added nitrogen.—The steadiness of the average increment given by sulphate of ammonia and nitrate of soda involves an equal steadiness in the average percentage recovery of the added nitrogen. During the period 1852–7, 40 per cent. of the nitrogen of the sulphate of ammonia had been recovered in the Hoosfield continuous barley crops, and a similar value 42·5 per cent. was obtained for the period 1903–7. No regular determinations were made in between, but the occasional data fit into the same range. But when deterioration of yield set in the recoveries became much lower, showing that the deterioration is associated with a lesser assimilation of nitrogen, not a lesser utilization. The recoveries on the continuous barley plots at Woburn were higher, ranging about 60 per cent. until deterioration set in.

TABLE 11. *Influence of Successively Increasing Doses* of Sulphate of Ammonia on Yield of Barley at Rothamsted and Woburn. Six-course Rotation Experiments. Mean of eight years, 1930–7*

						Increase for 1 part of nitrogen added	
	None	*1 dose*	*2 doses*	*3 doses*	*4 doses*	*1st dose*	*Mean of all doses*
	Grain, cwt. per acre						
Rothamsted .	25·6	26·8	28·6	28·2	29·8	8·0	6·5
Woburn .	15·9	20·3	23·7	25·6	27·2	29·3	18·6
	Straw, cwt. per acre					*Total produce*	
Rothamsted .	30·8	33·7	35·9	35·6	40·1	27·3	20·2
Woburn .	32·1	35·1	37·4	39·6	44·5	49·3	38·1

* 1 dose = 0·15 cwt. N per acre as sulphate of ammonia = 0·17 cwt. sulphate of ammonia per acre. Each plot receives a basal dressing of superphosphate (0·30 cwt. P_2O_5 per acre) and muriate of potash (0·50 cwt. K_2O per acre).

The recoveries from nitrate of soda are higher than those from sulphate of ammonia, and until deterioration set in were around 50 per cent. at Rothamsted and on the double-dressed plots at Woburn, and even higher on the Woburn plots receiving single dressings. After deterioration began the fall at Rothamsted was approximately the same as for sulphate of ammonia in presence of complete fertilizer, and also on the plot lacking phosphate, but it was less on the plots lacking potash.

On the farmyard-manure plots the recovery of nitrogen was at Rothamsted about 25 per cent., falling after deterioration had set in to 13 per cent., whilst at Woburn it was about 35 per cent., falling to 24 per cent. Here, however, the dressing was only half that given at Rothamsted (Table 12).

Dry matter formed per unit of nitrogen.—Whilst there is no strict proportionality, there is a certain connexion between the amount of nitrogen assimilated and the amount of carbohydrate synthesized. For each pound of nitrogen assimilated by barley roots under good conditions of growth about 80 or 85 lb. of dry matter is, under ordinary circumstances, produced in the plant. At low uptakes of nitrogen this figure changes but

little for successive increments of nitrogen supplied as fertilizer: the second increment may give somewhat higher or somewhat lower yields than the first. At higher uptakes of nitrogen, however, the amount of dry matter formed per unit of nitrogen assimilated becomes successively less with successive increases in uptake [15].

TABLE 12. *Percentage of Added Nitrogen Recovered in Grain and Straw**

(A) *Hoosfield Barley, Rothamsted*

Plots	*Mineral fertilizers*	*1903–7*	*1908–11*	*1913†*	*1914–18*	*1919–23*	*1924–8*	*Mean*
	Nitrogen as sulphate of ammonia (43 lb. N per acre)							
1A–1.0	No minerals	33	27	38	20‡	13	13	22
2A–2.0	Superphosphate	49	20	60	26	15	26	29
3A–3.0	Complete minerals except superphosphate	32	29	25	29§	16	17	24
4A–4.0	Complete minerals	39·8	34·25	43·5	24·25	42	29	38
	Mean	..	..	..	..	..	..	..
	Nitrogen as nitrate of soda (43 lb. N per acre)							
1AA–1.0	No minerals	41	39	51	25‡	23	23	31
2AA–2.0	Superphosphate	59	46	76	38	43	39	46
3AA–2.0	Complete minerals except superphosphate	38	30	46	29	13	16	26
4AA–4.0	Complete minerals	48·75	43·75	58	30·5	39	29	43
	Mean	..	..	..	..	..	..	..
	Farmyard manure (200 lb. N per acre)							
7.2–6.1	No minerals	25	23	26	15	15‖	13	18

(B) *Stackyard Field Barley, Woburn* [3]

Plots	*Mineral fertilizers*	*1882–6*	*1887–91*	*1892–6*	*1897–1901*	*1902–6*	*1907–11*	*1912–16*	*1917–21*	*1922–6*	*Mean*
	Nitrogen as sulphate of ammonia (41 lb. N per acre)										
2A–mean of 1 and 7	None	54	78	59	(Becomes negative)						64
5A–4A	Minerals	68	68	76	(Becomes negative)						71
	Nitrate of soda (41 lb. N per acre)										
3A–mean of 1 and 7	None	68	59	68	61	44	39	15	15	24	45
6–4A	Minerals (41 lb. nitrogen to 1906, 20·5 lb. 1907 onwards)	100	76	88	80	63	63	39	39	44	66
9A–9B	Minerals (82 lb. nitrogen to 1906, 41 lb. 1907 onwards)	50	45	46	51	50	41	24	29	27	40
	Farmyard manure 105 lb. N per acre till 1906, 82 lb. N afterwards										
11B–mean of 1 and 7	No minerals	39	22	39	32	32	40	30	37	24	33

* Calculated from nitrogen recovery in grain, assuming that 70 per cent. of the total nitrogen is present in the grain and 30 per cent. in the straw.
† After fallow in 1912. ‡ 1915 omitted. § 1916 omitted. ‖ 1922 omitted.

Seasonal fluctuations of the increments.—Although the increments per unit of added nitrogen at different centres tend to be similar over a period of years they vary widely from year to year. They tend to be higher in years of low basal yield, and lower in years of high basal yield, as is shown in Table 13, giving the coefficients of the regression equation relating the mean increment due to nitrogen to the basal yield without nitrogen.

The regression coefficients are all significantly negative.

We should thus expect the variation relative to the yield on the nitrogen-treated plots to be somewhat smaller than on those without nitrogen, and Fig. 1 shows that this is so, but the actual variation is greater (Table 7).

TABLE 13. *Relation of Size of Increment to Basal Yield without Nitrogen*

	Quantity of N added (lb. per acre)	*Mean yield without N*	*Mean increment due to N, per-cent. of yield without N*	*Regression co-efficient of increment on yield without N*
Rothamsted		*cwt. per acre*		
Institute of Brewing Experiments* (Rotation) 1922–32	23	15·7	26	−2·25±0·92
		bushels per acre		
Woburn, Stackyard Field (continuous) For sulphate of ammonia. Plots 5A–4A. 1877–94 .	41	23·4†	84	−3·65±1·23
For nitrate of soda. Plots 6–4A. 1877–1902 . .	41	21·7†	102	−3·65±0·93
For nitrate of soda. Plot 9. 1882–1906	82	28·1‡	75	−2·82±0·86

* The data for this set in cwt. per acre are:

Year	*1926*	*1931*	*1922*	*1925*	*1921*	*1924*	*1929*	*1932*	*1928*	*1927*	*1923*
Yield without N	22·25	15·7	14·1	11·6	13·6	10·2	20·1	28·2	14·4	12·5	9·75
Increment due to 1 cwt. sulphate of ammonia per acre	−1·67	1·2	2·2	2·8	3·4	3·65	4·2	4·6	5·2	6·0	6·65

† For plot 4A. The means differ because different periods of years are averaged.
‡ Mean for the half of plot 9 which received no nitrate of soda. The halves were treated in alternate years.

Action of rainfall in modifying the effects of nitrogenous fertilizers.—The fact that the Wishart-Mackenzie rainfall curves fall into groups corresponding with the manurial treatment indicates that the manures have modified the effects of rainfall, and rainfall has modified the effects of manures.

Additional rainfall in spring not only depresses the yield but also tends to reduce the effect of nitrogen: the increment of yield given by nitrogenous fertilizer is less in wet springs than in dry ones. This is shown in Table 14, giving figures read off from the Wishart-Mackenzie curves: the reduction in yield caused by one additional inch of rain at the time of maximum injury (March and April) is greater where sulphate of ammonia is given than where it is not.

At other times of the year, however, rainfall is less harmful, or more beneficial, to yields of plots receiving sulphate of ammonia than to the corresponding plots without it (Fig. 3).

On the other hand, as the figures also show, the *percentage* variation in yield due to variations in spring rainfall is less where nitrogen is supplied than where it is not.

TABLE 14. *Loss of Effectiveness of Nitrogenous Manures caused by one inch additional Rainfall in March and April*

Bushels per acre

	Complete minerals		*No phosphate*	*No potash*	*No potash or phosphate*
Mean yields:					
Sulphate of ammonia .	34·9	40·8	27·1	37·1	24·9
No nitrogen . .	16·2	19·8	15·0	19·6	14·0
Reduction caused by one inch additional rain in March and April:					
Sulphate of ammonia .	1·05	0·9	1·3	0·9	0·7
No nitrogen . .	0·8	0·5	0·75	0·6	0·7
Loss of effectiveness of sulphate of ammonia .	0·25	0·4	0·55	0·3	Nil

This depressing effect of April rainfall on the increment given by nitrogenous fertilizer is illustrated by the Institute of Brewing rotation series at Rothamsted. Here the regression coefficient[1] of the increment on April rainfall, $-1{\cdot}66 \pm 0{\cdot}67$ cwt. per inch, is negative and significant. The loss of effectiveness per inch of additional rainfall is considerably greater than that shown above for the Hoosfield data. A similar result is found if April and May rainfall is considered instead of April rainfall alone.

At Woburn, on the contrary, the opposite result is found and additional spring rainfall increases the increment of yield given by nitrogenous fertilizers. This is shown by the regression coefficients in Table 15, all of which are positive, and all significant except that for March rainfall which is nearly so.

The same conclusion follows from inspection of Miss Webster's rainfall curves [3]. The explanation of the discrepancy may be found in the difference in time of application of the nitrogenous fertilizer: at Rothamsted it is put in with the seed so that it is already in the ground when the rain comes, but at Woburn it goes on as a top dressing in late April or May, after the rain has fallen.

Comparison of different nitrogenous fertilizers.—Table 16 summarizes the results of experiments carried out to test different forms of nitrogenous fertilizers, comparing them on a basis of equal nitrogen-content.

[1] The increments and April rainfall for individual years were:

	1926	*1931*	*1922*	*1925*	*1921*	*1924*	*1929*	*1932*	*1928*	*1927*	*1923*	*Mean*
Increment of grain yield given by 1 cwt. sulphate of ammonia; cwt. per acre . . .	−1·7	1·2	2·2	2·8	3·4	3·65	4·2	4·6	5·2	6·0	6·65	3·48
April rainfall, inches .	2·96	3·46	3·52	1·70	1·57	3·18	1·61	2·34	0·91	1·86	1·48	2·24

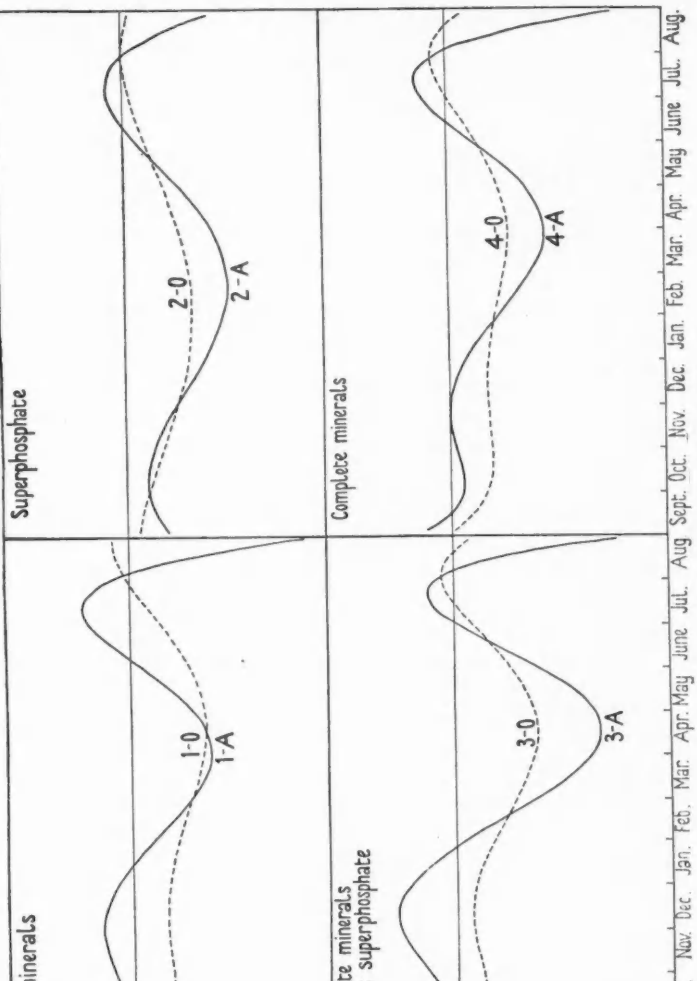

FIG. 3. Effect of rainfall on grain yield of Hoosfield plots.
Full lines: sulphate of ammonia. Dotted lines: no nitrogenous fertilizer.

TABLE 15. *Effect of March and April Rainfall on the Increment of Yield given by Nitrogenous Fertilizers*

Woburn continuous Barley, Stackyard Field

Nitrogenous fertilizer	*N given per acre (lb.)*	*Plots*	*Mean increment of grain yield (bushels per acre)*	*Mean rainfall (inches)*	*Regression coefficient of increment on rainfall (bushels per acre per in.)*
April rainfall					
Sulphate of ammonia (1877–94) . .	41	5A–4A	18·2	1·67	4·32±1·72
Nitrate of soda (1877–1902) . . .	41	6–4A	20·5	1·58	3·25±1·46
Nitrate of soda (1882–1906) . . .	82	9A–9B	19·2	1·46	4·57±1·90
March rainfall . .					
Sulphate of ammonia (1877–94) . .	41	5A–4A	18·2	1·22	5·42±2·74

TABLE 16. *Effect of Different Nitrogenous Fertilizers on Yield of Grain compared with that of Sulphate of Ammonia*

(Means for all experiments at Rothamsted and Outside Centres, 1922–35)

	Mean yield without nitrogen (cwt. per acre)	*Increase in yield due to sulphate of ammonia (0·2 cwt. N per acre)*	*Additional increment above that given by sulphate of ammonia (cwt. per acre)*	
			Single dressing (0·2 cwt. N per acre)	*Double dressing (0·4 cwt. N per acre)*
Nitro-chalk .	22·9	2·8	+1·8	..
Nitrate of soda .	21·1	2·3	+0·5	..
Muriate of ammonia . .	19·5	1·9	+1·2*	..
	15·4	3·9	+0·3	+1·8†
Ammonium bicarbonate .	20·8	3·3	−0·7	..
Urea . .	13·0	4·4	−0·4	+1·4‡
Cyanamide .	17·0	2·8	−0·2	−0·1†
Ammonium humate . .	26·2	2·6	−1·3	..

* Institute of Brewing series. Rate of application 1 cwt. of sulphate of ammonia per acre or equivalent muriate.

† Mean yield without nitrogen 16·7 cwt. per acre. Increase due to double dressing of sulphate of ammonia 4·7 cwt. per acre.

‡ Mean yield without nitrogen 15·4 cwt. per acre. Increase due to double dressing of sulphate of ammonia 5·0 cwt. per acre.

Muriate of ammonia[1] has consistently produced a slightly greater increase of grain yield than sulphate of ammonia. This superiority appeared in 8 out of 9 experiments at Rothamsted, and in 9 out of 11 experiments at other centres, though in individual experiments it was frequently not significant. On the mean of all experiments it amounted to 1·1 cwt. of grain for a dressing equivalent to 0·2 cwt. nitrogen per acre, and to 1·8 cwt. for a double dressing.

Of the other fertilizers used, nitrate of soda has usually given better yield increases than sulphate of ammonia, in agreement with the results of the Hoosfield and Stackyard field experiments. In the two experiments (Rothamsted 1929 and 1930) in which a direct comparison of nitrate of soda with muriate of ammonia was made, nitrate of soda was slightly the more effective, but not significantly so. Nitro-chalk has given better increases than sulphate of ammonia. Urea and cyanamide differed very little in their effectiveness from sulphate of ammonia.

Influence of time of sowing on effectiveness of nitrogenous fertilizers.—Late-sown barley benefits less from nitrogenous fertilizer than early sown. This is shown in an experiment at Rothamsted in 1932 when three varieties of barley, Plumage Archer, July, and Victor were compared at two times of sowing, one early (March 4–8) and the other late

[1] There is a little evidence that other chlorides have a beneficial effect on barley yields. In experiments made by the Bath and West of England Society in 1889 (*J. Bath and West of England Soc.*, 1890, **21**, 230–75), application of agricultural salt increased both grain and straw yield in 18 out of 19 experiments. The increase was greater than that produced by muriate of potash, but the potash and salt were not applied at equivalent rates. .The mean yields were:

	No salt or muriate of potash	*Salt*	*Muriate of potash*
Grain cwt. per acre . .	19·2	20·6	19·6
Straw cwt. per acre . .	22·3	25·0	23·8

All plots received 1½ cwt. of nitrate of soda, and 2 cwt. superphosphate. Salt was applied at the rate of 3 cwt. per acre, and muriate of potash at ¾ cwt. per acre.

In two experiments made in the Institute of Brewing series salt gave no significant increases.

Yield of grain, cwt. per acre

	Salt			
	No salt	*100 lb. per acre*	*300 lb. per acre*	*S.E.*
Sparsholt 1929 . .	23·9	24·1	24·4	±0·74

	No salt or muriate of potash	*Muriate of potash* (1)	*Salt* (2)	*Muriate of potash* (1) *and salt* (2)	*S.E.*
Wye 1930	19·4	20·0	20·2	20·3	±0·77

Rates of application: (1) 1 cwt. per acre.
(2) 88 lb. per acre.

(April 6): one set of plots received sulphate of ammonia whilst the others did not. The results were:

Grain, cwt. per acre

	Plumage Archer		*Victor*		*July*	
	Sown early	*Sown late*	*Sown early*	*Sown late*	*Sown early*	*Sown late*
Sulphate of ammonia .	32·9	25·8	29·4	26·5	21·2	18·1
No nitrogen . . .	27·0	24·2	25·7	24·9	18·4	15·7
Gain due to nitrogen .	5·9	1·6	3·7	1·6	2·8	2·4

Straw, cwt. per acre

Sulphate of ammonia .	36·5	39·4	26·6	26·1	20·0	19·1
No nitrogen . . .	29·3	36·5	23·4	22·6	18·3	16·0
Gain due to nitrogen .	7·2	2·9	3·2	3·5	1·7	3·1

Except for the low-yielding variety, July, the grain yield increased much more on the early-sown plots than on the late ones: the straw, however, showed this effect only for the vigorously growing Plumage Archer.

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THE ROTHAMSTED FIELD EXPERIMENTS ON BARLEY 1852–1937

Pt. II. EFFECTS OF PHOSPHATIC AND POTASSIC FERTILIZERS DETERIORATION UNDER CONTINUOUS CROPPING

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Effects of Phosphatic Fertilizers

Few field experiments are more striking than those showing the effects of superphosphate on barley growing on land deficient in phosphate. Between the phosphate-starved barley at Rothamsted and that well supplied with phosphate there are remarkable differences in growth and appearance: the phosphate-starved barley makes poor root-development [1], it tillers but little, is late in sending out the ear from the ensheathing leaves, and is late in ripening. Throughout growth it has a greyish colour, in striking contrast to the bright green of its neighbours supplied with phosphate, whilst leaf-sheath and stem both frequently have a red coloration. For some ten days after the fully-manured plants have turned a golden yellow in the later summer, the phosphate-deficient crop is still greenish and unripe. This slower maturation makes it susceptible to insect attack, particularly the gout fly (*Chlorops teniopus*, Meig.) and direct counts show a larger infestation on this plot than on others [2]. At harvest the yield is depressed by some 7 cwt. per acre (Table 1).

Table 1. *Hoosfield. Yield of Grain in cwt. per acre*

	*Complete Artificials**		*Phosphate omitted*		*Reduction in yield by omitting phosphate*	
	N as nitrate of soda	*N as sulphate of ammonia*	*N as nitrate of soda*	*N as sulphate of ammonia*	*N as nitrate of soda*	*N as sulphate of ammonia*
Plot	*4AA*	*4A*	*3AA*	*3A*		
1st 4 years 1852–5 . .	..	24·0	..	21·8	..	2·2
20 ,, 1852–71 . .	..	23·5	..	17·8	..	5·7
20 ,, 1872–91 . .	20·9	20·5	14·7	13·7	6·2	6·8
20 ,, 1892–1911 . .	19·2	19·1	12·2	11·1	7·0	8·0
15 ,, 1914–28† . .	15·1	14·7	8·7	8·6	6·4	6·1
4 ,, 1929–32 . .	15·9	15·9	6·7	4·9	9·2	11·0
2 ,, 1935–6 . .	27·0	27·2	21·4	19·0	5·6	8·2

* 3½ cwt. superphosphate, 200 lb. sulphate of potash, 100 lb. sulphate of soda, 100 lb. sulphate of magnesia, and 206 lb. sulphate of ammonia or 275 lb. nitrate of soda, per acre.

† In 1912 and in 1933 the plots were fallowed and in 1913 and 1934 the yields were exceptionally high. These two years are therefore omitted.

Effects of this magnitude, however, are rarely obtained in practice, and they were not seen in any of the other experiments.

In the Institute of Brewing and other recent rotation experiments at Rothamsted the effect of superphosphate on tillering is small. In none of the experiments except Hoosfield was any hastening of maturation observed, but no test could be devised as simple as that of counting

tillers, and small effects might easily be missed. In the Institute's large-scale experiments for the period 1922–33 the effect of omitting superphosphate from the manuring was small as compared with the omission of nitrogen; it was as follows:

Yield of Grain (*cwt. per acre*)

	Mean	Reduction by omission of		
		Nitrogen	Phosphate	Potash
1922–5 . .	19·1	2·9	0·6	0·35
1927–33 . .	23·2	2·9	0·7	0·25

Superphosphate was usually beneficial only on the Norfolk light loams: here, however, it always increased yields, a result of considerable technical importance because of the large amount of barley grown on these soils (Table 2).

TABLE 2. *Effect of Superphosphate* on Yield of Barley: Rotation Experiments* (*cwt. per acre*)

Average 3 years	Rothamsted Heavy loam		Woburn Light soil		Norfolk centres Light soil		Lincoln Heath Limestone	
	Yield without superphosphate	Gain from superphosphate	Yield without superphosphate	Gain from superphosphate	Yield without superphosphate	Gain from superphosphate	Yield without superphosphate	Gain from superphosphate
1922–3–4 .	17·0	−0·6	18·4	Nil	16·1	3·0	22·8	−0·2
1925–6–7 .	19·0	1·6	16·2†	0·5	21·8§	1·6	21·5	1·6
1928–9–30 .	17·9	−0·2	24·0‡	0·9	..	..	17·4‖	0·5
2 years 1931–2	23·6	1·1	..	..	..	..	30·2¶	−0·6
Average .	17·9	0·4	19·4	−0·1	17·5	2·7	22·0	0·5

* 3 cwt. per acre, 1922–8, later 0·4 or 0·5 cwt. P_2O_5 per acre.
† 1925, 1926 only. ‡ 1928 and 1929 only.
§ 1925 only. ‖ 1929 and 1930 only. ¶ 1931 only.

The reason for this ineffectiveness of superphosphate on barley is that, in practice, barley is grown either immediately after, or within two years of a root or other crop liberally manured with phosphate. A few years' abstention from phosphatic manuring, however, sufficed to reduce the yields on Hoosfield and Little Hoosfield considerably below the phosphate treated plot:

Superphosphate omitted for	1	2	3	4	5	6	7	11	16	18	19 years
Percentage reduction of yield:											
Hoosfield . . .	5	4	21	8	14	31	39	14	29	21	19
Little Hoosfield (*a*) .	23	26	27	..	..	..	..	..	..	..	..
(*b*) .	3	..	..	..	..	8	..	35	53	70	45
Four-course Rotation Experiment (*c*) . .	3	12	4	9	..	..	..	..	..	..	..

(*a*) Average for six barley crops 1905, 1909, 1914, 1919, 1921, 1922.
(*b*) Comparison of fully-manured plot with plot receiving no phosphate throughout the experiment.
(*c*) Average for three years 1934–6.

We can offer no explanation of the high results on the Little Hoosfield (*a*). Apart from these it appears that the effects of omitting phosphate from the manuring for a few years may not cause much reduction in crop, but omission for longer periods markedly lowers the yield. This result is of considerable practical importance, because, with the shrinkage of the area under roots, the likelihood of heavy application of phosphate is becoming less and there is the danger of insufficiency. The substitution of fallow for roots emphasizes the need of phosphate, for as shown in Table 14, the increment given by superphosphate after a fallow was greater than usual.

Influence of Soil Type on the Effectiveness of Phosphate

There seems to be no clear connexion between soil type and effectiveness of phosphate. Tables 2 and 3 suggest that the light Woburn soil is less responsive than the heavy Rothamsted soil, but the difference is small and not significant, and does not seem to be a general property of light and heavy soils. Perhaps the most striking difference is that occasionally the crop on light soils is depressed by superphosphate.

TABLE 3. *Six-Course Rotation. Average eight years, 1930–1937*

	No phosphate	*1 dose**	*2 doses*	*3 doses*	*4 doses*	*Mean increment per cwt. P_2O_5 per acre*
	Grain, cwt. per acre					
Rothamsted	27·0	26·2	28·6	28·9	28·1	3·3±2·0
Woburn	23·7	24·2	25·1	24·0	24·4	0·8±1·2
	Straw, cwt. per acre					
Rothamsted	34·5	34·2	36·1	38·3	36·1	4·9±2·8
Woburn	38·0	36·6	39·4	37·0	38·4	0·8±2·7

* 1 dose = 0·15 cwt. P_2O_5 as superphosphate.

Phosphate and Late-sown Crops

In view of the effect of superphosphate on the root-formation and maturation of plants, an experiment was made in 1932 to see whether late-sown barley could be so expedited in growth by superphosphate as to enable it to catch up with an earlier sown crop. The results are shown in Table 4: the superphosphate increased the yield, but it had no significantly greater effect on the late-sown than on the early-sown crop.

The late-sown crops failed to produce quite as much total dry matter as the early ones. Plumage Archer, the heaviest yielder among them, failed still more to transfer the material to the grain when sown late. The early-sown Plumage Archer yielded 48 parts of grain for each 100 parts of total produce, but the late one gave only about 40 parts. The other varieties, however, showed only very slight differences. Phosphate apparently caused a slight increase in the proportion for Plumage Archer and July, but not for Victory.

Occasional Apparent Adverse Effect of Superphosphate on Barley-yield

Although it has not been observed at Rothamsted, there have been occasional instances on the light soils of depression in yield produced by

superphosphate. This happened at Orwell (the lightest soil of the series) in 1922 and 1924, at Woburn in 1924, 1925, 1928, and 1929, at Chiselborough in 1925, and at Wellingore in 1929. In the six-course rotation experiment at Woburn, depressions of the yield of grain were recorded in 1930, 1934, 1935, and 1936, and of the yield of straw in 1931, 1932, 1933, and 1936, but none was statistically significant. If the effect is real, the simplest explanation is that under certain weather conditions

TABLE 4. *Effect of Superphosphate on Early and Late Sown Barley. Rothamsted, 1932*

Variety	*Plumage Archer*		*Victory*		*July*		*Standard error*
Sowing-date	*Mar. 6*	*Apr. 6*	*Mar. 6*	*Apr. 6*	*Mar. 6*	*Apr. 6*	
			Grain, cwt. per acre				
Superphosphate	30·5	25·8	28·2	26·5	20·0	17·4	±0·96
No superphosphate	29·4	24·2	27·0	25·0	19·5	16·6	
Increment due to superphosphate	1·1	1·6	1·2	1·5	0·5	0·8	±1·36
			Straw, cwt. per acre				
Superphosphate	32·0	38·8	25·6	26·0	19·0	17·4	±1·10
No superphosphate	33·8	37·1	24·4	22·8	19·3	17·7	
Increment due to superphosphate	−1·8	1·7	1·2	3·2	−0·3	−0·3	±1·56
			Grain per 100 parts total produce				
Superphosphate	49	40	52	50	51	50	
No superphosphate	47	39	53	52	50	48	

Superphosphate was applied at the rate of 0·5 cwt. P_2O_5 per acre.

ripening may already be somewhat too rapid for optimal yield on these light soils, and that the addition of superphosphate hastens it still more, and so cuts off the production of dry matter before it would otherwise have ceased.

Influence of Season on the Effectiveness of Phosphatic Fertilizers

All three of the main effects of phosphate on barley—on root-development, tillering, and hastening of maturation—are so important in relation to weather conditions that one would expect rather sharp relationships between effectiveness of phosphate and rainfall. The Wishart-Mackenzie curves for the Hoosfield data [3] do in fact show a relationship with the rainfall of the period December to February preceding sowing (Fig. 1): the benefit of the phosphate is less after a wet than after a dry winter: a result also obtained in another way by R. A. Fisher.[1] On the heavy Rothamsted soil, therefore, it appears that phosphate is more helpful to the young plant in rather dry than in wet conditions. Later on in the plant's life the effect seems to be reversed, and superphosphate reduces the harmful effect of April rain: on plot 4A (complete artificials) one additional inch of rain in April lowers the yield by 0·9 bushels, whilst on the adjoining plot 3A without phosphate the reduction is 1·3 bushels per

[1] He found a negative correlation between winter rainfall (September–February), and response to phosphate for the plots receiving nitrate of soda and superphosphate, and nitrate of soda only.

Alkali salts
No sulphate of ammonia or alkali salts

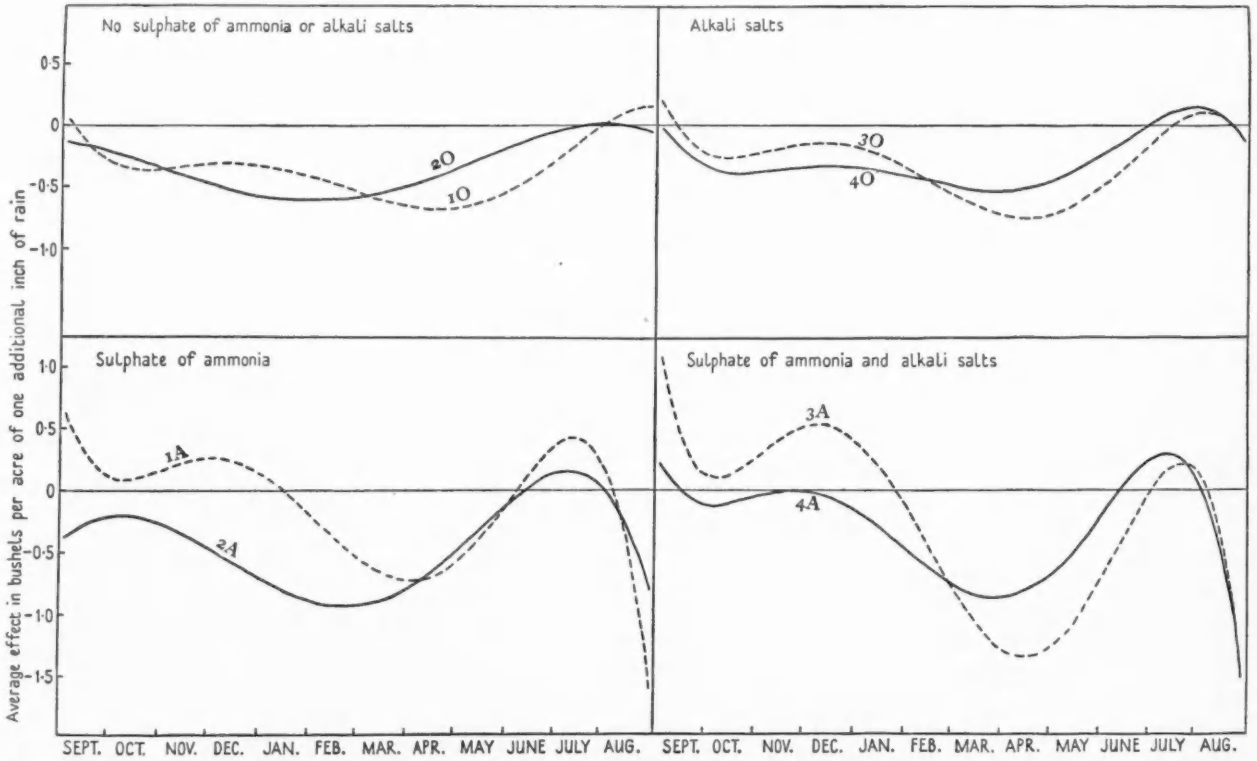

FIG. 1. Effect of rainfall on grain-yield of Hoosfield plots. Full lines: with superphosphate. Dotted lines: without superphosphate.

acre. The effect of the phosphate is therefore greater when April rainfall is higher. These winter and April rainfall effects are frequently masked by others which are not yet known. In the shorter series of rotation experiments they appear in individual years both at Rothamsted and at Woburn, but not sufficiently frequently to have statistical significance.

Effect of Potassic Fertilizers on the Yield of Barley

Potassic fertilizers have had little effect on the yield of barley either at Rothamsted or the other centres. For the first thirty years of the Hoosfield experiment the yields of barley on the plots without potassic fertilizer (Series 2) were almost exactly the same as on those that received it (Series 4). Then, however, differences began to appear and the yield of the plot without potash, but with superphosphate and sulphate of ammonia (Plot 2A), fell some 4 to 6 bushels behind that receiving sulphate of potash also (Plot 4A). For the past 15 or 20 years the plants on 2A have shown all the signs of potash starvation—dying at the tips of the leaves, yellowing of the edges, a dull grey colour and a general flaccid appearance. Those at the edges of the plots, however, remain quite healthy. So far the story appears quite simple: actually it is more complex. These potash starvation symptoms do not appear on any other of the plots without potash. Where no nitrogen is given we may suppose that the yields are too low to have exhausted the supplies in the soil; and where rape cake is given (p. 306) one would not expect potash starvation, since the dressing of rape cake supplies about 13 lb. K_2O per acre. The fact that the symptoms do not show on Plot 2AA, which receives nitrate of soda, might be put down to the well-known power of sodium to economize or replace potassium in the plant.

The difficulty arises from the fact that the plots in Series 4 receive not only sulphate of potash but also 100 lb. per acre of sulphate of soda and of sulphate of magnesia: the comparison is thus not between potash and no potash, but between potash, soda, and magnesia and none of these. Another plot received sulphate of ammonia, superphosphate, and sulphate of potash only, without soda or magnesia, and if the fertility of the field were uniform this would give the effect of the potash alone.

The results of the comparison are rather surprising. Over the years 1852 to 1928 the average yields per acre have been:

	Sulphate of ammonia and superphosphate alone (2A)	*Sulphate of ammonia, superphosphate, and sulphate of potash* (5A)	*Sulphate of ammonia, superphosphate, and sulphates of potash, soda, and magnesia* (4A)
Grain, bushels per acre . .	35·8	33·8	39·3
Increase over 2A		−2·0	+3·5
Straw, cwt. per acre	20·4	21·7	23·6
Increase over 2A		+1·3	+3·2

Taking the figures as they stand, sulphate of potash has depressed the yield of grain whilst the sulphate of soda and magnesia have distinctly

increased it. The result seems absurd, and, as 5A is some distance from 2A and 4A, one might explain it by the very probable assumption that the soils differed in fertility, and therefore the plots are not comparable. Mackenzie [4], however, has adduced evidence that they are comparable, and supposes that the sulphate of potash renders more soluble, and therefore more liable to loss by leaching, some unknown element important for the growth of barley, whilst neither sulphate of soda nor sulphate of magnesia has this effect. An alternative explanation would be that sodium or magnesium is more important to barley than potassium, but there is no other evidence of this.

Series 2 and 4 make a better comparison, because in each case the plots are nearly adjacent: but of course no separation is possible of the three salts. The mean increases due to these alkali salts over the period 1852 to 1928 have been:

	No Nitrogen		*Sulphate of Ammonia*		*Nitrate of Soda*	
	Grain	*Straw*	*Grain*	*Straw*	*Grain*	*Straw*
	bu. per acre	*cwt. per acre*	*bu. per acre*	*cwt. per acre*	*bu. per acre*	*cwt. per acre*
No superphosphate .	0·9	0·9	2·1	2·3	0·2	1·2
Superphosphate .	Nil	2·4	3·5	3·2	−1·1	0·5

The completely manured plot 4AA (nitrate of soda, superphosphate, and alkali salts) has given a slightly smaller average yield than 2AA from which the alkali salts are omitted. But this has not always been so: for the first 20 years the yields were practically the same; then the difference appeared and it has usually been about 1 or 2 cwt. per acre. Thus the alkali salts, which are beneficial in conjunction with sulphate of ammonia, are slightly harmful with nitrate of soda. The action is probably complex and is not confined to the nitrate of soda plots; on three out of four pairs of plots examined [4] alkali salts increase the rate of deterioration of the yields: the exception is plot 4A (sulphate of ammonia, superphosphate, and alkali salts), where alkali salts have retarded the rate of deterioration as compared with plot 2A (Table 5).

TABLE 5. *Mean Annual Diminution of Yield, 1852–1921 (bushels per acre). Hoosfield*

	No Nitrogen		*Sulphate of Ammonia*	
	No superphosphate	*Superphosphate*	*No superphosphate*	*Superphosphate*
Alkali salts	0·216	0·197	0·291	0·192
No alkali salts	0·192	0·155	0·259	0·353
Mean annual diminution of effect of alkali salts	0·024	0·042	0·032	−0·161

No explanation of these results can be given: there is, however, considerable probability that they are real.

Barley grown in rotation.—Potassic fertilizers have had little or no

effect on barley grown in rotation. The mean effect on yield of grain produced by 1½ cwt. of sulphate of potash in fifty-one experiments of the Institute of Brewing series, carried out at many centres in the years 1922–6, was $-0{\cdot}11 \pm 0{\cdot}316$ cwt. per acre. In a second series, in the period 1927–33, where the rate of application was 1·2 cwt. per acre of sulphate of potash, the mean increase was $0{\cdot}25 \pm 0{\cdot}22$ cwt. per acre. The effects varied from season to season, and at no centre was there a consistent increase. At Rothamsted the increases of yield have been, in cwt. per acre:

1922	*1926*	*1925*	*1923*	*1930*	*1929*	*1924*
+2·8	+0·85	Nil	Nil	Nil	−1·0	−2·3

and at Wellingore:

1929	*1923*	*1930*	*1931*	*1925*	*1932*	*1922*	*1924*
+1·2	+1·0	+0·5	+0·3	Nil	Nil	−2·25	−3·75

The variation between seasons is presumably related to seasonal weather conditions, but the series of experiments is too short to enable the individual weather factors responsible for the variations to be detected.

In the six-course rotation experiments at Rothamsted and Woburn, in which muriate of potash is given in four different quantities, potash has not significantly increased the yield of barley grain on the average of all years (1930–7), though it did so in individual years (Rothamsted 1937, Woburn 1932, 1933), and in one year (Rothamsted 1936) it gave a significant decrease. It has, however, somewhat increased the yield of straw (Table 6).

TABLE 6. *Six-Course Rotation Experiments. Rothamsted and Woburn. Means for eight years (1930–1937)*

*Units of potash**	*0*	*1*	*2*	*3*	*4*	*Mean increment per cwt. of K_2O per acre*
	Grain, cwt. per acre					
Rothamsted	27·4	29·1	29·3	28·6	28·2	$70{\cdot}3 \pm 1{\cdot}80$
Woburn	21·9	24·3	25·0	23·5	24·0	$2{\cdot}27 \pm 2{\cdot}51$
	Straw, cwt. per acre					
Rothamsted	32·9	35·1	36·6	36·3	38·1	$7{\cdot}73 \pm 1{\cdot}55$
Woburn	35·9	36·8	38·0	39·2	38·4	$4{\cdot}93 \pm 1{\cdot}44$

* 1 unit = 0·25 cwt. K_2O per acre as muriate of potash.

Interactions between Nitrogenous and Potassic and Nitrogenous and Phosphatic Fertilizers

With some crops, notably sugar-beet and potatoes, potassic and nitrogenous fertilizers on some occasions mutually reinforce each other's action, so that the two together produce greater effects than the sum of their separate effects. We can find no evidence that this happens for

barley. At Rothamsted any interaction would in any case be difficult to detect because of the small effects of the potassic fertilizers. At Woburn, on the other hand, potassic fertilizers have on occasions been distinctly effective, but in no case was there any reinforcement of the action of nitrogenous manures (Table 7).

TABLE 7. *Interaction of Nitrogen and Potash* (*Mean of no Phosphate and Phosphate Plots*). *Woburn. Yield of Grain in cwt. per acre*

	No nitrogen or potash	*Nitrogen*	*Potash*	*Nitrogen and potash*	*Standard error*
1928 . .	15·0	19·3	20·5	18·2	±1·45
1929 . .	24·6	28·7	30·3	28·5	±1·70

In each year a maximum was reached with either nitrogen or potash beyond which the yield did not rise, some other factor limiting the yield; the two fertilizers interacted so as to reduce each other's effect.[1]

Between nitrogenous and phosphatic fertilizers on Hoosfield, however, there appears to be a definite positive interaction, for the effect of the two fertilizers given together is much greater than the sum of their effects when given alone:

	Yield of grain in cwt. per acre Average 1852–1928
Yield for unmanured land (1O)	6·9
Increment due to nitrogen alone (1A–1O)	5·2
,, ,, phosphate alone (2O–1O)	2·7
,, ,, alkali salts alone (3O–1O)	0·4
	15·2
Yield from completely fertilized plot (4A)	19·9
Excess due to using phosphate and nitrogen and alkali salts together instead of singly	4·7

Influence of Rainfall in Modifying the Action of Potassic Fertilizers

The Wishart-Mackenzie curves (Fig. 2) show that on Hoosfield, alkali salts tend to reduce the harm done by winter rainfall to the yield of barley: they thus tend to counteract the adverse effect of excessive winter rain on the phosphate plots: this alleviation appears in all cases where comparison is possible.

The relations to summer rainfall are more definite. In dry seasons the alkali salts are more effective than in wet ones: i.e. their action on the yield of barley grain is negatively correlated with the rainfall during the period April to June.

Over the period 1891–1928[2] the mean increase of yield of barley grain due to alkali salts has been 59·7 lb. per acre.

The regression coefficients of the increment of yield due to alkali salts on rainfall in lb. per acre per inch of rain are:

April to June rainfall . . .	−55·23±24·43
July to August rainfall . .	−19·57±21·64
April to August rainfall . .	−33·43±15·59

[1] On sandy soils in Germany Wiessmann and Schramm [5] found that the effect of nitrogen was enhanced by the addition of potassic fertilizer, and vice versa.

[2] This period was taken because the sunshine records began in 1891.

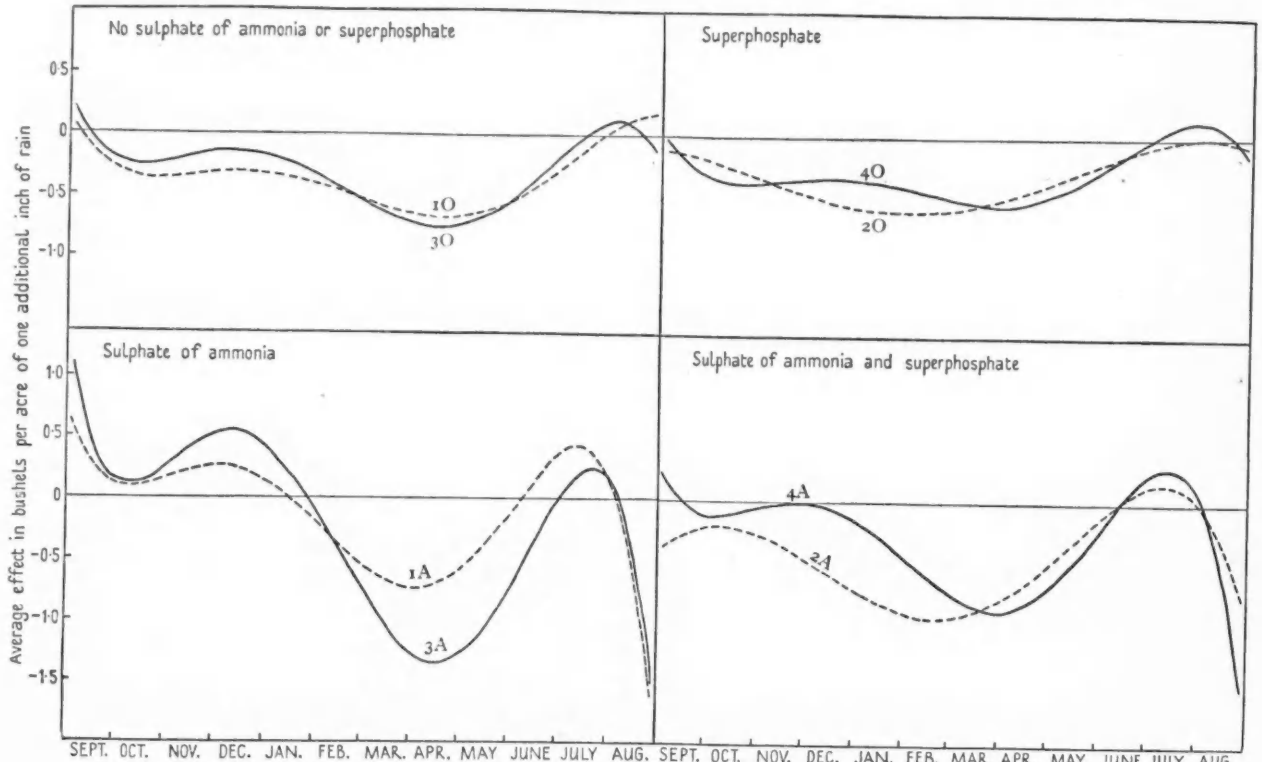

FIG. 2. Effect of rainfall on Hoosfield plots. Full lines: with alkali salts (sulphates of potash, soda, and magnesia). Dotted lines: without alkali salts.

Of these, however, the July–August rainfall effect is not significant although both the others are, indicating that the main effect is in the three months April, May, and June.

However, as rainfall and sunshine are negatively correlated over the whole of this period, the facts could equally well be taken to prove that alkali salts act best in sunny seasons. The regression coefficients of the increment on hours of sunshine in lb. per acre per hour are:

April to June sunshine	$0{\cdot}922 \pm 0{\cdot}581$
July to August sunshine	$0{\cdot}979 \pm 0{\cdot}560$
April to August sunshine	$0{\cdot}874 \pm 0{\cdot}373$

On general grounds it seems more probable that the effect is attributable to moisture rather than to sunshine.

A multiple regression fitted on the four variates together gave regression coefficients as follows:

April to June sunshine	$0{\cdot}654 \pm 0{\cdot}602$	lb. per acre per hour of sunshine.
July to August sunshine	$0{\cdot}626 \pm 0{\cdot}587$	,, ,, ,,
April to June rainfall	$-42{\cdot}58 \pm 28{\cdot}06$	,, inch of rain.
July to August rainfall	$-11{\cdot}51 \pm 8{\cdot}21$	,, ,, ,,

None of these is individually significant, nor does the regression on all four variates account for a significant proportion of the total variance. The regression coefficients are smaller than when the variates are fitted singly.

There was no indication of any variation of these effects resulting from the presence or absence of either nitrogen or phosphate in the fertilizer.

The beneficial effect of the alkali salts in dry seasons can be seen in the field; the barley receiving them ripens less rapidly than where none is given. The leaves retain their green colour longer and dry out more slowly.

Unfortunately it is not possible to say what part of these effects is due to the potassium, and what part to the sodium and magnesium salts. There is, however, other evidence that potassium salts facilitate the uptake of water in dry seasons, and also that the amount of water transpired, per unit of dry matter produced, is reduced by increase in potassium supply.

The average rainfall at Rothamsted is greater than that required for optimum yield, and additional rain at almost all times during the growing season decreases the yield. The small action of potassic fertilizers may be attributed in part to the circumstance that they exert their greatest effect in the drier seasons.

The effect of potassium on the strength of barley straw was investigated by Tubbs [6]. Potassium starvation decreased the strength of the lower internodes, but increased the strength of the middle internodes. It might, therefore, be expected that the addition of a potassic fertilizer would reduce the tendency of the crop to lodge; this, however, has not been consistently observed on the Hoosfield plots though it is seen very strikingly on the Park Grass plots.

Pot experiments by Gregory and Richards [7] have shown that potassium deficiency causes a reduction of assimilation rate and an increase of respiration rate, and both these effects would tend to reduce the amount

FIG. 2. Effect of rainfall on Hoosfield plots. Full lines: with alkali salts (sulphates of potash, soda, and magnesia). Dotted lines: without alkali salts.

of dry matter accumulated in a given time. Later, they found that the effect of potassium depended on the level of calcium and sodium supply. With low calcium and high sodium, a reduction of potassium supply did not effect meristematic activity (i.e. tillering), leaf-production or leaf-size, but the leaves were pale yellow, and had a high water-content and a low carbohydrate-content. On the other hand, with abundant calcium and low sodium—conditions that occur on Hoosfield—a reduction of potassium supply restricted meristematic activity; the leaves were smaller and darker green in colour, with a tendency to produce red pigmentation; they had a low water-content, but the carbohydrate-content was not diminished.

The withholding of potassic fertilizer has far less effect on barley than on wheat. On the Broadbalk wheat plots the mean yield of grain for the period 1852–1925 on plot 13, which receives complete artificials, has been 17·0 cwt. per acre, and on plot 11, where potash is omitted, only 12·3 cwt. per acre, a reduction of nearly 28 per cent. This suggests that barley has a greater power of obtaining potassium from the soil than has wheat, when growing in similar conditions. In spite of its shorter period of growth a barley crop contains approximately as much potash as a correspondingly treated wheat crop (Table 8).

TABLE 8. *Potash-content of Barley and Wheat Crops* (*lb. per acre*) [8]
(*Hoosfield and Broadbalk. Means of 40 years, 1852–91*)

	Plot no.	Potash-content		
		In grain	*In straw*	*In total produce*
Barley				
Completely manured	4A	13·9	39·5	53·4
Without potash	2A	12·2	13·2	25·4
Wheat				
Completely manured	13	10·8	39·6	50·4
Without potash	11	8·0	15·4	23·4

Farmyard Manure

The farmyard-manure plot has given on the average 2·5 cwt. more grain and 15·7 cwt. more straw per acre than the plot receiving complete artificial fertilizers. This superiority showed itself only after the first ten years, but it does not appear to widen as the years go by (Table 9). Mackenzie found that the farmyard-manure plot has a smaller annual variation in yield, and a smaller relative variance due to weather, than any of the other plots, though the complete artificials plot runs it very close. Farmyard manure thus has a steadying effect on crop yield. There is also less deterioration than on the plot receiving complete artificials. It is not necessary to invoke any special properties to explain these results: the wide difference in the quantity of nitrogen supplied (about 200 lb. by the farmyard manure: 43 lb. by the artificials) probably accounts for them.

An extension of this experiment, however, gives one of the most remarkable of all the Rothamsted results, for which we can offer no explanation.

In 1872, after the first twenty years of the experiment, the farmyard-manure plot was divided into two parts, one of which (7–2) continued to receive farmyard manure annually, whilst the other (7–1) has since been unmanured. The yield on 7–1 fell off rapidly, but even after 65 years it is still some 3 to 5 cwt. of grain above that of the plot which has been unmanured since the beginning of the experiment.

TABLE 9. *Residual Effect of Farmyard Manure. Grain, cwt. per acre. Ten-year Averages*

	Farmyard manure each year	*Farmyard manure 1852–71, then no manure*	*No manure*			*Complete Artificials*	
						Sulphate of ammonia	*Nitrate of soda*
Plot no.	*7–2*	*7–1*	*6–1*	*6–2**	*1O*	*4A*	*4AA*
1852–61	22·7		12·6	12·1	11·4	23·2	..
1862–71	26·7		9·6	10·2	8·8	23·8	24·0†
1872–81	25·7	17·4	6·9	7·7	6·8	20·9	21·7
1882–91	23·7	13·0	7·7	8·2	6·2	20·0	20·1
1891–1901	22·9	10·6	5·6	6·1	5·3	18·0	18·5
1902–11	23·6	9·7	5·4	7·1	5·2	20·1	19·8
1913–22‡	18·3	10·8	7·8	9·2	6·4	17·9	18·6
1923–32	15·7	7·2	3·4	4·5	3·6	13·6	13·6
1934–37‡	27·9	16·0	10·5	11·3	7·2	24·3	24·1
Mean:							
1852–1937	22·7	..	7·5	8·3	6·7	19·9	19·3§
1872–1937	22·0	11·7	6·4	7·4	5·7	18·8	19·1

* Received ashes from laboratory furnace, 1852–1933; afterwards unmanured.
† 1868–71. ‡ No crop in 1912 and 1933 (Fallow). § 1868–1937.

The difference can hardly be put down to soil heterogeneity, for a similar result was obtained on another set of plots on Hoosfield, the old permanent potato plots, which for 26 years (1876–1901) had received annual dressings of 14 tons of farmyard manure and were then discontinued and cropped with cereals without further manure. The results for the last four crops for which yields were recorded are given in Table 10.

TABLE 10. *Residual Effect of Farmyard Manure. Old Potato plots, Hoosfield*

	Plot 1 Unmanured since 1876		*Plot 3 Dung 14 tons per acre annually for 26 years, 1876–1901, afterwards unmanured*	
	Grain	*Straw*	*Grain*	*Straw*
	bush.	cwt.	bush.	cwt.
1918 Barley	8·4	4·0	16·2	8·6
1919 Barley	4·7	3·2	11·5	6·4
1921 Wheat	10·5	9·1	24·3	24·6
1922 Barley	13·0	7·4	21·6	11·3

They indicate that a succession of annual dressings of dung produces some permanent effect which continues to show for many years, at any rate where the level of cropping is low.

Effect of weather on the effectiveness of farmyard manure.—Wishart and Mackenzie showed that winter rain (December to March) has a much more harmful effect on the yield of the farmyard-manure plot than on the yields of any of the plots receiving only artificial fertilizers (Fig. 3). The superiority of farmyard manure over artificial fertilizers is thus greater after a dry winter than after a wet one.

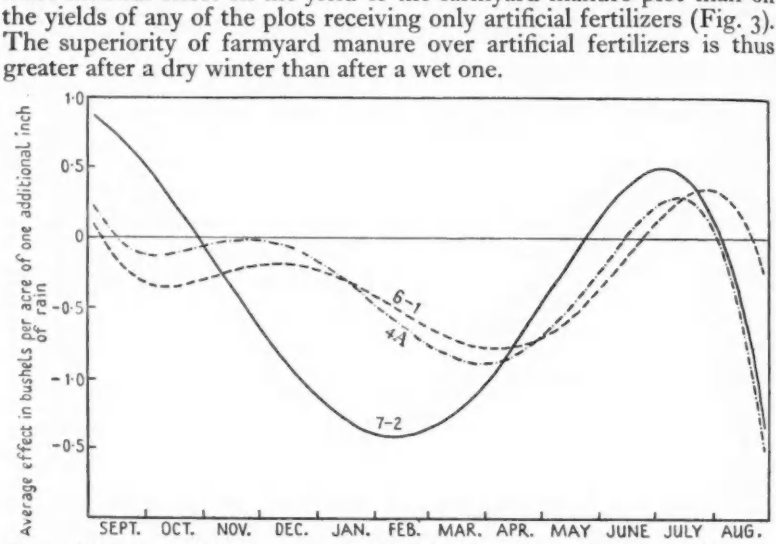

FIG. 3. Effect of rainfall on grain-yield of Hoosfield plots. Full line: farmyard manure Dot-dash line: complete artificials. Broken line: unmanured

There is, however, no evidence that farmyard manure is superior to artificial fertilizers in dry springs or summers: the effect of rainfall from April onwards is substantially the same both for farmyard manure and for artificial fertilizers.

Rape Cake

Rape cake was used as fertilizer in all the classical Rothamsted experiments, and it acts very well. The samples used in recent years contained the following:

	Old samples [9]	*1934*	*1935*	*1936*
N	5·0	5·33	5·20	5·60
P_2O_5	2·0	2·53	2·47	1·85
K_2O	1·3	1·48	1·44	0·99

The dressing of 100 lb. per acre thus supplies about 54 lb. nitrogen, 23 lb. P_2O_5, equivalent to 150 lb. superphosphate, and 13 lb. K_2O, equivalent to 25 lb. muriate of potash.

The rape cake provides all the elements of plant food and gives yields of 4 to 5 cwt. per acre above those of the plots receiving no nitrogen or no phosphate. The amount of potash supplied is sufficient for optimal yield, but the amount of phosphate is not: addition of superphosphate raises the average yield to within one cwt. per acre of those on the plots receiving complete artificial fertilizers. The phosphate in the crop has not been

determined every year, but a certain number of analyses have been made and, accepting these as averages, we may suppose that the additional crop given by the rape cake contains about 5 or 6 lb. P_2O_5 per acre, corresponding to an uptake of about 25 per cent. of the phosphorus in the rape cake, a figure which appears to be higher than the recovery from superphosphate, probably because the quantity of phosphate given in the rape-cake dressing is small. There is an accumulation of phosphoric acid in the soils of these plots receiving rape cake. The yields are given in Table 11.

TABLE 11. *Hoosfield Barley. Yield of grain in cwt. per acre. Five-year Means*

	1C Rape cake only	*2C* Rape cake and superphosphate	*3C* Rape cake and alkali salts	*4C* Rape cake + alkali salts + superphosphate
1852–56	22·2	22·4	20·7	22·2
1857–61	24·6	25·5	23·6	25·3
1862–66	23·9	25·2	23·8	25·8
1867–71	21·1	22·1	21·0	23·0
1872–76	20·2	21·3	18·9	21·6
1877–81	19·5	21·1	19·2	21·1
1882–86	19·0	20·8	18·5	19·9
1887–91	16·0	17·3	15·0	15·7
1892–96	17·7	19·5	17·3	19·0
1897–1901	14·4	14·7	13·0	14·2
1902–06	17·6	19·4	18·3	20·5
1907–11	17·3	17·3	16·4	19·2
1913–16*	20·6	21·6	20·0	21·2
1914, 15, 16†	18·7	19·3	17·4	18·6
1917–21	7·8	8·9	6·0	6·4
1922–26	12·8	15·5	10·7	15·2
1927–31	10·2	14·2	9·3	12·7
1932–36*	22·6	28·3	22·3	28·0
1932, 35, 36†	20·4	26·2	20·6	25·6

* 4 years. † Average (3 years) excluding the year following the fallow. Fallow in 1912 and 1933.

Those for the period 1917–21 were low because rape cake was unobtainable during these years; they are very little higher than on the plots without nitrogen, showing that the rape cake has left but little nitrogenous residue in the soil.

The plots treated with rape cake and artificial fertilizers have lower pH values than any others excepting 4A (sulphate of ammonia and complete minerals) (Table 12).

TABLE 12. *pH of the Soil of Hoosfield Plots, 1932*

	Alone	*+Superphosphate*	*+Alkali salts*	*+Superphosphate and alkali salts*
Rape cake	7·2	6·8	6·5	6·2
Nitrate of soda	7·8	8·0	7·6	6·9
Sulphate of ammonia	8·0	7·6	7·1	5·6
Farmyard manure	7·1	..	..	..

This might be attributed to initial irregularities in the distribution of the chalk, which is known to have been applied to the soil many years ago. It may, however, be an effect of rape cake on the soil, for at Woburn the plots receiving rape cake year after year are also more acid than any others except those receiving sulphate of ammonia (Table 13).

TABLE 13. *pH of Soil of Stackyard Field Plots, Woburn*

	Barley			*Wheat*		
	1888	*1927*	*1932*	*1888*	*1927*	*1932*
Rape cake	6·0	4·9	5·1	6·2	5·4	5·4
Farmyard manure	6·1	5·8	5·8	6·0	6·4	5·9
Complete artificials						
N as nitrate of soda	6·2	5·8	5·8	6·0	6·1	5·8
N as sulphate of ammonia	5·5	4·8	4·7	5·4	4·8	5·1

Effect of Soil Reaction on the Yield of Barley

At Woburn the long-continued use of sulphate of ammonia rendered the soil acid and finally incapable of producing normal yields of barley. No such falling off, however, has been observed at Rothamsted. In spite of the repeated applications of sulphate of ammonia the pH values of the Hoosfield soil in 1932 still remained above 7, with the exception of the rape-cake plots and of plot 4A, where the pH was 5·6. We can offer no explanation of the low value for plot 4A, and can only attribute it to an initial difference in the dressing of chalk given to the soil many years ago.

The value 5·6 is still above that at which the barley began to fail at Woburn (5·3).

Effect of Fallowing

Fallowing has been remarkably effective in raising the yield of the succeeding crop. Bare fallows were given in 1912 and in 1933 on Hoosfield. In both cases the yields of the following crop were comparable with the highest attained during all the years of the experiment (Table 14).

TABLE 14. *Effect of Fallowing in 1912 and in 1933 on Yield of Barley: Hoosfield*

Grain, cwt. per acre

Plot	*Treatment*	*1913*	*Average previous 5 years*	*Gain due to fallowing*	*1934*	*Average previous 5 years*	*Gain due to fallowing*
7–2	Farmyard manure	32·4	22·5	9·9	34·2	15·8	18·4
	Complete artificials						
4A	N as sulphate of ammonia	31·6	19·2	12·4	33·5	13·7	19·8
4AA	N as nitrate of soda	32·0	19·1	12·9	32·7	13·7	19·0
3A	As 4A, but no phosphate	18·3	10·8	7·5	14·8	4·9	9·9
2A	As 4A, but no alkali salts	31·8	13·1	18·7	30·8	13·1	17·7
4O	As 4A, but no nitrogen	21·4	7·5	13·9	34·9	7·8	27·1
1O	No manure	10·8	4·9	5·9	15·2	3·5	11·7
	Total Produce, cwt. per acre						
7–2	Farmyard manure	64·4	54·9	9·5	76·3	40·4	35·9
	Complete artificials						
4A	N as sulphate of ammonia	60·5	45·1	15·4	66·9	29·7	37·2
4AA	N as nitrate of soda	63·2	45·6	17·6	71·5	30·5	41·0
3A	As 4A, but no phosphate	35·2	27·1	8·1	37·5	15·2	22·3
2A	As 4A, but no alkali salts	58·4	30·6	27·8	60·3	27·2	33·1
4O	As 4A, but no nitrogen	41·2	21·2	20·0	71·1	18·5	52·6
1O	No manure	20·7	11·2	9·5	37·2	8·9	28·3

In 1934 nine of the plots attained closely similar yields of 33·5 to 35 cwt. per acre, and in 1913 seven of them had attained yields of 30 to 32 cwt. per acre. The previous maximum without fallow had been 28–32·5 cwt. per acre in 1854, which was nearly reached again in 1863 when 29–31 cwt. were obtained. The similarity of these figures is very remarkable and suggests that about 35 cwt. per acre of grain and 42 cwt. of straw (making 77 cwt. per acre of total produce) represent a maximum yield for this field which we have not exceeded in any season or by any treatment known to us.[1]

A remarkable feature of these crops was that they all stood up well and the grain had a low content of nitrogen. Whatever the cause of the extraordinary high yield it was not simply excess of nitrogenous nutrients: this invariably causes high nitrogen-content of grain and nearly always results in lodging.

The chief difference between the two sets of results is that the yields on the plots without nitrogen, e.g. 4O and 1O, were much lower in 1913 than in 1934, and in consequence the effect of added nitrogen was more pronounced. This may be associated with the much higher rainfall in the winter preceding the 1913 crop: October 1912–March 1913, 15·56 in.; October 1932–March 1933, 8·72 in.

During the fallow a considerable quantity of nitrate accumulates in the soil. Much of this was probably washed out by the high rainfall of the six months October 1912 to March 1913, and in consequence the nitrogenous manures were able to exert their effect: the increment given was 10·2 cwt. of grain for the 43 lb. nitrogen against the previous 5 year average of 11·7. In 1934, however, there was much less leaching, and in consequence the added nitrogen was without effect.

Although the effect of the fallow survived the very wet winter of 1912–13 it did not survive more than the one crop of 1913. The fallow of 1933 seemed to be more persistent, and could still be seen in 1935, but only on the plots supplied with nitrogenous manures. On the plots without added nitrogen the yields were below the average: on those with nitrogenous manure, however, they were well above, the increment for the 43 lb. of nitrogen being 15·4 cwt. of grain, corresponding to an uptake of 80 per cent. of the added nitrogen, instead of the average increment of 10 cwt. The results suggest that fallowing either removes something harmful from the soil, or liberates something that promotes growth, but does not long persist in the soil.

Deterioration of Yield under Continuous Cropping with Barley

The polynomial curves fitted to the yields of the different plots [4] fall into three groups corresponding with the manurial treatments (Fig. 4). They stop at 1921 so that they take no account of the recent yields. The groups are:

1. *No nitrogen supplied:* including the unmanured plots. Deterioration was rapid during the first four decades, though proceeding more slowly at the end, then in the late 90's the yields began to improve.

[1] In 1938 the yield of grain on the farmyard-manure plot was 38 cwt. per acre, but the highest yield with artificial fertilizers was 23 cwt.

2. *No phosphate supplied:* Deterioration was rapid during the first few years, then for a time in the 60's there was no further fall. Afterwards the fall recommenced and continued till the late 90's, after which there was a rise.

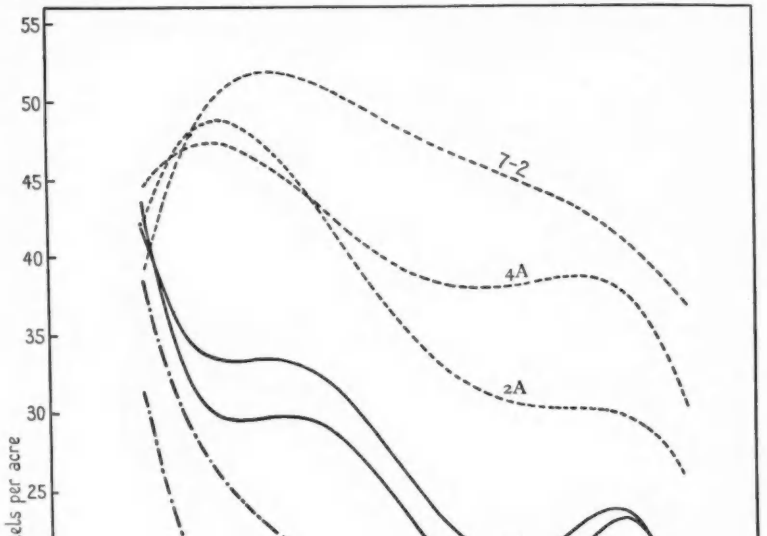

FIG. 4. Smooth curves (fifth order polynomials) fitted to the yields of dressed grain. Hoosfield, 1852–1921 [4]. Treatments: Group I (dot-dash line), 1O, unmanured; 4O, complete minerals, no nitrogen. (The curves for plots 2O (superphosphate only) and 3O (alkali salts only) are very similar to those of 4O and 1O respectively. They are omitted for the sake of clarity.) Group II (full line), 1A, sulphate of ammonia only; 3A, sulphate of ammonia and alkali salts. Group III (broken line), 2A, sulphate of ammonia and superphosphate; 4A, complete artificials; 7–2, farmyard manure

3. *Nitrogen and phosphate both supplied:* including plots receiving complete artificials and farmyard manure. For the first few years there was not only no deterioration but a rise in yield. Then came a fall which

has continued since. There is no marked rise in the late 90's, as in the other groups.

Each curve can be analysed into a linear component, which expresses the effect of continuously and uniformly acting factors, and a non-linear component, representing factors which act continuously but not uniformly so that they sometimes operate one way and sometimes another, though the change is only slow. Such factors include weeds, soil-borne fungi, insects persisting in the soil, and other effects which operate from year to year, but to a varying extent, each year's action, however, having some relation to that of the preceding year. Even the changes in farm managers and foremen, with their varying efficiencies, are reflected here. On Hoosfield these factors are not important except on the plots without nitrogen. They are less significant than for the Broadbalk wheat.

The linear component, representing a steady fall of yield over the whole period, is almost certainly due to soil deterioration, resulting from the exhaustion of substances essential to plant-growth or other continuous changes in the physical or biological conditions influencing plant-growth. These are important on all plots excepting those receiving farmyard manure and complete artificials.

The rates of deterioration are all greater than on the Broadbalk wheat field, even on the plot receiving farmyard manure, where deterioration is slowest. This may be associated with the shorter period of growth of the barley, and its more shallow-rooted habit of growth.

The deterioration on the plots receiving no nitrogen or no phosphate can readily be explained by supposing that these essential nutrients become exhausted from the soil.

It is much more difficult to account on chemical or physical grounds for the deterioration of yield on the plot receiving farmyard manure each year (plot 7–2). The fall in yield does not begin early, as on the unmanured plots or those lacking nitrogen or phosphate: it appears only during a part of the time, before and after which the yields fluctuate about the same steady value (Table 9). This period of low yields is from 1917 to 1931, and the fall was particularly marked in the years 1927–31: after this the yields rose to their original level. It is not, however, necessary to invoke any soil or climatic reasons for this bad period. It was bad for all the plots, and part of the low yield can be attributed to the human factor. The year 1917 and those immediately following were exceptionally difficult for all field experimental work because of the disorganization due to the war; when this was over, a new field staff had to be trained because the old staff, who knew the plot work well, was gone, and the period 1925–31 was particularly trying. By 1932 the troubles were overcome and from thenceforth the management has been stable and satisfactory.

It is at least possible, therefore, that this period of low yield is not due to any soil deterioration, but to these purely personal and transient factors which have now been overcome.

Similar considerations apply to the plot receiving complete fertilizers. Here, however, there is better evidence of deterioration, as the fall in

yield began after 1866, though the very low yields between 1922 and 1931 can probably be explained in the same way as those on the farmyard-manure plot. Some deterioration of yield might be expected because of the loss of organic matter from a soil continuously cropped with barley, and without farmyard manure or a clover-ley. The loss, however, is not very great, as Table 15 shows.

TABLE 15. *Percentage of Carbon and of Nitrogen in Dried Samples of the top 9 inches of soil. Hoosfield*

	Plot 4A: artificial fertilizers only			*Plot 7–2: farmyard manure annually*	
Date of sample	*1868*	*1882*	*1913*	*1882*	*1913*
C	..	1·082	..	2·486	..
N	0·112	0·110	0·112	0·213	0·266

Plot 7–2 contains about twice as much organic matter as Plot 4A and it receives five times as much nitrogen annually; yet the difference in yield is only 2 cwt. per acre. In none of the experiments at Rothamsted does barley show any pronounced need for organic manure.

Since the plots without nitrogen have shown greater deterioration than the plots receiving nitrogen, the increments given by the nitrogen have been greater for the smaller yields of grain than for the large ones, and this is shown in Table 16. The period 1914–32 falls out of line with the others, but this contains the bad years already discussed.

The ratio of grain to total produce also seems to be unaffected by the deterioration: it fluctuates from season to season and it falls off when the

TABLE 16. *Increment of Yield of Barley given by added Nitrogen. Rothamsted, Hoosfield* (*0·38 cwt. N*)

	As sulphate of ammonia		*As nitrate of soda*		*Yield per acre without nitrogen*	
	Plot 4A–4O		*Plot 4AA–4O*		*Plot 4O*	
	Grain	*Total produce*	*Grain*	*Total produce*	*Grain*	*Total produce*
	bushels	*lb.*	*bushels*	*lb.*	*bushels*	*lb.*
1st 4 years (1852–55)	10·1	1,873	..	..	36·9	4,343
20 years (1852–71)	18·8	2,655	..	..	27·5	3,162
20 years (1872–91)	23·5	3,014	24·0	3,180	17·2	1,897
20 years (1892–1911)	23·0	2,753	22·6	2,952	14·3	1,979
10 years (1914–23)	14·7	1,510	15·6	1,709	18·0	2,254
9 years (1924–32)	14·1	1,511	14·6*	1,688	11·7	1,939
3 years (1935–37)	20·8	2,127	18·8	2,128	21·0	3,320

* 1931 omitted because series AA and AAS were mixed together in error.

yields are very low, but it shows no steady downward trend and within wide limits no relation to yield [10].

Effect of Undersowing with Clover

It is usual in Great Britain to sow clover in the barley soon after the seedlings have begun to appear. In sand cultures, clover is known to supply nitrogen to a non-leguminous crop growing with it, but there is no evidence that this happens in soil. In some of the Rothamsted experiments an estimate can be obtained of the effect of the clover on the barley; it is in all cases positive, but small, and not statistically significant.

A comparison of barley alone with barley undersown with various crops gave results shown in Table 17.

TABLE 17. *Effect of Undersowing on Yield of Barley. Grain, cwt. per acre*

Rothamsted

Barley undersown with:	*No Ley*	*Clover*	*Rye-grass*	*Clover and rye-grass*	*S.E.*
1931					
Grain, cwt. per acre	16·1	17·3	15·8	16·0	±0·80
Increase over barley alone		1·2	Nil	Nil	..
Nitrogen, per cent. in grain	1·71	1·72	1·69	1·69	..
1936					
Grain, cwt. per acre	23·8	26·6	25·2	23·7	±1·00
Increase over barley alone		2·8	1·4	Nil	..

Woburn 1937

Green manure for kale	*Mustard*		*Tares*		
Barley undersown with:	*No clover*	*Clover*	*No rye-grass*	*Rye-grass*	*S.E.*
Grain, cwt. per acre	12·0	12·4	13·4	11·2	±0·484
Increase over barley alone		0·4		−2·2	..

A small non-significant increase was also obtained at Woburn in 1937; here the barley followed kale which had been green manured, some with mustard and some with tares.

The Agdell field rotation experiment (Table 18) shows increases in barley undersown with clover, as compared with barley sown alone, but here there is some uncertainty whether the increases are due to the clover growing with the barley, or to residues of clover grown in the previous rotation. As the increases are of the same order as in the 1931 and 1936 Rothamsted experiments (Table 17), it may be that they are in part at any rate associated with the growing clover:

TABLE 18. *Effect of Undersowing. Agdell Field. Average of 22 Courses 1848–1935*

	Unmanured		*Minerals only No nitrogen*		*Complete artificials*	
Barley undersown with:	*No clover*	*Clover*	*No clover*	*Clover*	*No clover*	*Clover*
Grain, cwt. per acre	20·8	19·0	22·1	26·0	29·1	33·6
Increase over barley alone		−1·8		3·9		4·5

The results indicate the probability of a small benefit from clover, which, however, is nothing like as clear as that obtained from a dressing of 20 lb. nitrogen per acre in the form of sulphate of ammonia or nitrate of soda. One can safely say that undersowing with clover does no harm, and may do good, whilst undersowing with rye-grass does no good to the barley growing with it.

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THE RELATION OF PHOSPHATIC MANURING TO POTASH-DEFICIENCY SYMPTOMS ON THE POTATO CROP

G. A. COWIE

In a series of twenty-four replicated trials which I carried out in the season 1937 to test the effects of phosphates, potash, and another salt on the potato crop, a new and interesting observation was made regarding the type of fertilizer dressing that induces the symptoms of potash deficiency usually associated with the potato crop.

The experimental design adopted was the $3 \times 3 \times 3$ single replication, involving three randomized blocks of nine plots each and all combinations of three levels of the fertilizers, the error being estimated from higher order interactions. A basal dressing of nitrogen was applied equally to all the plots. The levels of phosphates and potash tested per acre, in the form of superphosphate and sulphate of potash respectively, were: (1) nothing, (2) 54 lb. phosphoric acid, (3) 108 lb. phosphoric acid; and (1) nothing, (2) 87 lb. potash (K_2O), (3)174 lb. potash (K_2O).

The experiments were carried out generally on acid sandy soils of low fertility, without the addition of dung, for the purpose of securing as large a response as possible to the minerals to be tested.

About a week or two after the appearance of the plants above ground, interesting differences became obvious between the plots which received nitrogen only and those which received nitrogen with phosphates at both levels, in each case without potash. The NP plants in most cases germinated earlier, grew away more quickly, and developed a bushier habit of growth than the N plants. At ten centres potash-deficiency symptoms became very marked on certain of the plots which did not receive a potash dressing, but these symptoms were observed only on the plots which received both nitrogen and phosphates without potash. The N and NP plants were substantially darker in colour than the KPN plants, but the difference in colour between N and NP plants was not marked, except that the leaves of the NP plants were shinier and glossier than those of the N plants. The N leaves showed little or no crinkling, but almost a flat upper surface, like that of KPN plants, whilst the NP leaves were markedly crinkled on the upper surface in the early stages, a symptom which has been regarded as the first indication of potash deficiency. The subsequent browning or 'coppering' of the tissue between the veins and the development of marginal scorch with premature death of the haulms were observed only on the NP plants. On the other hand, the N plants appeared normal, although stunted, throughout their growth, and died off similarly to, and sometimes later than, the KPN plants, with a yellowing of the leaves from the bottom upwards.

It has been assumed hitherto that a high level of nitrogen with low potash was the primary condition for the production of potash-deficiency symptoms, but in the case of potatoes phosphates certainly play an essential part. Further investigation is proceeding with a view to ascertaining the effect of phosphates at different levels of nitrogen.

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THE INFLUENCE OF THE NUTRITIONAL CONDITION OF LAMBS ON THEIR SUSCEPTIBILITY TO AN ARTIFICIAL INFESTATION WITH PARASITIC NEMATODES

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Introduction.—The importance of the nutritional state of the host on its susceptibility to parasitic helminths is now generally recognized. We have previously reported an experiment on sheep [1] which supported the results of earlier pioneer work by Foster and Cort with dogs [2]. Our experiment on sheep, however, was open to certain justifiable criticisms. The procedure therein adopted was to produce a wide difference in bodily condition, due to nutrition alone, in parasite-free lambs; to graze the lambs on heavily worm-infested pasture for a period; to slaughter the lambs at the end of the grazing period, and to count certain species of nematodes contained in their fourth stomachs at the time of slaughter. Using this method it was found that the average number of *Haemonchus* contained in the stomachs of 16 lambs well fed after the grazing period was 31; whereas the corresponding number for an equal number of lambs poorly fed after the grazing period was 103 [1]. The conclusion drawn was that, owing to their relatively poor nutrition before being exposed to infection, the poorly fed lambs had a greater susceptibility to infestation with *Haemonchus*, and consequently contained a greater number at slaughter.

Now it is a matter of common observation that the daily grazing period of lean sheep is longer than that of fat sheep. It might therefore be argued that the result we obtained was due simply to the fact that our poorly fed group of lambs when put out to graze worm-infested pasture ate more grass (even although special precautions were adopted to avoid this source of error), and consequently ingested more infective nematode larvae than our well-fed group of lambs. In short, it might be argued that the statistically significant difference in worm-burden we obtained was due to a difference in the dosage of the parasite rather than to a difference in the susceptibility of the host. Such argument is to a certain extent supported by a later observation made by us that when parasite-free lambs are put out to graze worm-infested pasture, the number of worms found in them at slaughter is rather closely correlated with the live-weight gains made by them while grazing [3].

It therefore appeared necessary to repeat our previous experiment, but on this occasion avoiding the possible fallacies due to grazing, by keeping

the lambs throughout the experiment on a quantitatively controlled and worm-free diet, securing an equal chance of infestation by artificially infesting each individual lamb with a known dosage of worms.

Methods

Animals.—Worm-free lambs were obtained as follows. The lambs were allowed to have their first drink from their dams, and thereafter kept separate from all other sheep in concrete pens bedded with sawdust. The lambs were fed cows' milk and concentrates, without fodder of any kind. Repeated examination of faeces showed that the lambs remained parasite-free.

Feeding.—When between 2 and 3 months of age, the lambs were divided into two groups of 20. From then (18. v. 37) onwards until slaughter (8. ix. 37), a period of 113 days, one group (hereafter referred to as the 'well-fed' group) was fed a full production ration, while the other group (hereafter referred to as the 'ill-fed' group) was fed a ration sufficient to maintain life but not for normal growth.

The ration of the well-fed group was:

A. *Concentrates*

	Per cent.		*Per cent.*
Earthnut cake	4·0	Sharps	16·0
White fish-meal	4·0	Pea- or lentil-meal	19·0
Ex. soya-bean meal	6·0	Rice-meal	10·0
Linseed-cake meal	6·0	Ground chalk	3·0
Locust-bean meal	12·5	Salt	0·6
Ground maize	16·25	Cod-liver oil	0·9

Fed *ad lib.*

B. Cows' whole milk : 4–4½ lb. daily.

The ration of the ill-fed group was:

A.

			Per cent.
Crushed oats	1 part	Chalk	2·0
Bran (medium)	1 part	Salt	1·0
Cooked maize	1 part	Cod-liver oil	0·5

B.

No milk.

These rations were modified later in the experiment in that separated milk was substituted for whole milk in the ration of the well-fed group on grounds of expense; and a certain amount of separated milk was fed to the ill-fed group because some lambs in it were becoming too weak.

Administration of infective larvae.—In an experiment of this kind the two essentials for an absolutely decisive experiment are lambs initially parasite-free, which we were successful in securing, and a pure culture of large numbers of infective larvae of one species of parasitic nematode which, unfortunately, in the present stage of helminthological technique is difficult to obtain. We were therefore forced to use a mixed culture of infective larvae secured from incubated sheep faeces as our infective

agent. We endeavoured, however, to ensure that each lamb dosed received an approximately equal number of infective larvae. It is necessary to describe the technique adopted in some detail. We are of the opinion that in view of the number of sheep used in the experiment and of the wide difference in worm-infestation between the two groups ultimately established, any minor errors produced by our method of dosage are unimportant.

The following method was used:

The recta of newly killed lambs were collected daily from the slaughter-house. The faeces were emptied on to a tray, moistened slightly if necessary, and crumbled lightly with a glass rod. They were then transferred to a Kilner jar which was charged up to one-third of its capacity. The rubber band at the top was removed, the glass lid placed on, and the screw-cap loosely fitted. It is important that the cultures should receive plenty of air. Diarrhoeic faeces were not used. The jars were kept in the dark at 25–27° C. It was found that cultures kept in an oven were often poor, and that the most satisfactory results were obtained using a large wooden box fitted with a darkened electric bulb. This method allowed of greater circulation of air. Every few days a few drops of water were added to the cultures and the sides of the jar moistened with a camel-hair brush.

The unimportant *Strongyloides* spp. appear in cultures in 2–3 days, *Haemonchus*, *Ostertagia*, *Trichostrongylus* in 4–5 days, *Chabertia* in 6–7 days, and *Nematodirus* in 14 days. By keeping the cultures from 7–14 days, depending on the time of collection of the faeces, all the important species should have reached the infective stage. On the day before the lambs were dosed, the cultures were exposed to diffused sunlight. It has been recommended [4] that half an hour in the light is sufficient, but it was found that greater numbers were recovered by leaving the cultures overnight.

The doses were prepared by the following method. Approximately 40 lambs were to be dosed, each being given 20 c.c. of the 'infective fluid', i.e. 800 c.c. had to be prepared for each dosage. Using lukewarm water the larvae were washed off the sides of the jar and transferred to a graduated cylinder. Two or three washings were required to remove all the larvae. Care was taken to prevent too much faecal contamination. The washings were made up accurately to 800 c.c. Using a fine-bored pipette, 0·1 c.c. of this mixture was drawn off and transferred to a small glass staining-well. Under a low-power dissecting microscope it was possible to distinguish between the unimportant *Strongyloides* spp., the saprophytic free-living forms, and the other parasitic infective larvae (Note—for brevity the larvae of *Haemonchus*, *Ostertagia*, &c., will be referred to as 'parasitic larvae'). It was, however, not possible by this method to estimate the numbers of the different species of parasitic larvae. Counts of the total number of parasitic larvae were made. Five or six samples were drawn off and the average count taken. In this way the approximate numbers of parasitic larvae in each 20 c.c. dose could be estimated.

A 20 c.c. pipette was used to measure off each dose, which was then transferred to a small glass tube fitted with a cork. The mixture was

stirred thoroughly during this operation to ensure a uniform sample. It is important that the doses be prepared almost immediately before the treatment of the lambs, as it was found that the larvae kept in tightly stoppered tubes for a few hours became lethargic.

The lambs received their doses by stomach-tube.

The following is the summary of the doses administered to each individual lamb:

Date	*No. of parasitic larvae*
June 18	1,500
June 30	2,200
July 14	6,000
July 28	4,500
August 11	6,000
August 25	8,500
Total	28,700

The lambs were slaughtered on September 8, 1937. The worms were isolated from the ingesta of the fourth stomach and counted by the method previously described by us [5].

Results

Mortality.—During the experiment 4 lambs died. Three of these were in the ill-fed and 1 in the well-fed group. The cause of death requires a short discussion. It is improbable that the worm-infestation was responsible. The casualty in the well-fed group occurred before the first infestation was performed. The three casualties in the ill-fed group occurred after infestation. Indeed, infestation was found to have an ill-effect on all lambs in the ill-fed group, producing intestinal disturbance and loss of appetite. Nevertheless, this pathogenic effect of infestation cannot be attributed to the infective larvae themselves, since it was found that the administration of the culture heated to 60° C. to kill the larvae, or of the culture filtered to remove the worms, had a precisely similar pathogenic effect when administered to a control group of worm-free lambs. It is probable that the worm-culture contained toxins, and that these toxins were responsible for the pathogenic effects observed.

Weight.—The great difference in the plane of nutrition between the two groups naturally resulted in a correspondingly wide difference in weight and condition at the close of the experiment. Thus:

	Well-fed group	*Ill-fed group*
Average live-weight (in lb.) at the beginning of the experiment (18. v. 37)	32·3	31·5
Average live-weight at end of the experiment (8. ix. 37)	100·5	41·0
Average weight of carcass	48·9	17·3

Worm-burden.—There was an equally great difference in the number of worms recovered from the fourth stomachs of the lambs on slaughter.

Count of Worms present in Fourth Stomach of Lambs

ILL-FED GROUP

No. of lamb	*Ostertagia sp.*	*Haemonchus contortus*	*Trichos. axei*
1	260	80	Nil
2	200	40	,,
3	120	40	,,
4	7	40	,,
5	140	140	,,
6	140	40	,,
7	180	60	,,
8	160	20	,,
9	240	40	,,
10	320	100	,,
11	260	220	,,
12	600	80	,,
13	160	80	,,
14	340	160	,,
15	240	80	,,
16	260	40	,,
17	250	104	30
18	225	68	15
19	250	101	Nil
	4,352	1,533	45
Average	229	81	3

WELL-FED GROUP

No. of lamb	*Ostertagia sp.*	*Haemonchus contortus*	*Trichos. axei*
1	9	1	Nil
2	18	Nil	,,
3	23	1	,,
4	10	2	,,
5	30	Nil	,,
6	72	6	,,
7	1	3	,,
8	4	1	,,
9	5	6	,,
10	2	Nil	,,
11	14	1	,,
12	Nil	2	,,
13	8	5	,,
14	6	Nil	,,
15	2	3	,,
16	6	Nil	,,
17	2	2	,,
18	4	Nil	,,
19	3	Nil	,,
	219	33	
Average	11	2	

Discussion

The results of this experiment show the profound effect of nutrition on the resistance of lambs to an artificial worm-infestation. Every lamb

in both groups received approximately the same number of infective worm larvae. The only known difference between the two groups of lambs was that one was well fed, the other ill fed. At the time of slaughter the average number of worms recovered from the stomachs of the well-fed lambs was: *Ostertagia* 11, *Haemonchus* 2, *Trichostrongylus* 0. In the stomachs of the ill-fed lambs the corresponding figures were: *Ostertagia* 229, *Haemonchus* 81, *Trichostrongylus* 3. Such a clear-cut result requires no statistical analysis.

The infestation produced in both groups was a light one and almost certainly not pathogenic. Nevertheless, the effect of the nutrition of the lamb in resisting infestation is quite clear.

In considering this result the more direct effect of food in relation to intestinal parasites must be kept in mind. The relation is possibly of a different nature from that obtaining in a bacterial or virus invasion of a host. It is evident that the conditions localized to the intestines may have an important influence on the host's resistance to intestinal parasites. Of probable importance is the amount of food contained in the intestine —what may be roughly called the bulk factor. It is conceivable that the chances of an infective helminth larva obtaining an attachment to the intestinal mucosa are increased by relative emptiness and lessened motility of the host's gut. In the experiment described the bulk of food consumed by the well-fed group was more than double that consumed by the ill-fed group, and this difference in the bulk of the food eaten may conceivably have influenced the degree of worm-infestation artificially established. On the other hand, the increased resistance to worm-infestation as a result of good feeding may have been an expression of an increased general vitality of the host. The question, one of considerable interest, is suitable for experimental investigation but cannot be clarified by the results of the experiment described.

Summary

Two groups of 20 parasite-free lambs were artificially infested with an approximately equal number of infective nematode larvae. The only known difference between the two groups was that one group was well fed, the other ill fed. On the lambs being slaughtered and the contents of their fourth stomachs examined, it was found that the ill-fed lambs had retained a much greater number of larvae than those well fed. The average count for the ill-fed group was, *Ostertagia* 229, *Haemonchus* 81, *Trichos. axei* 0. The corresponding figures for the well-fed group were, *Ostertagia* 11, *Haemonchus* 2, *Trichos. axei* 0.

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FURTHER EXPERIMENTS WITH CULTIVATED TROPICAL FODDER CROPS

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1. THE research on tropical fodder crops, begun at the Imperial College of Tropical Agriculture in 1932 [1, 2, 3], has been continued during the three years 1934–7. In September 1934 the more promising species of fodder grass were tested in a factorial experiment involving eight replications and a plot-size of $\frac{1}{57}$ acre. The treatments were:

Varieties: Guatemala Grass (*Tripsacum laxum* Nash.).
Para Grass (*Panicum barbinode* Trin.).
Sugar-cane (*Saccharum sinense* Var. Co. 213).

Cutting Rotations: A. Harvested every 8 weeks.
B. Harvested every 12 weeks.

Spacing, manuring, method of eliminating border rows, and harvesting technique were similar to those described previously [2]. The experiment lasted from Jan. 7 to Dec. 9, 1935, equivalent to six harvests of the eight-week rotation and four harvests of the twelve-week rotation. Coimbatore 213 cane was used, as it has proved to be superior to Uba cane, the one more commonly planted in Trinidad for fodder production [3].

TABLE 1. *Yield of Herbage* (*lb. per plot*)

	Series A, 8-week rotation				*Series B, 12-week rotation*		
Date of cutting	*Para Grass*	*Guatemala Grass*	*Sugar-cane*	*Date of cutting*	*Para Grass*	*Guatemala Grass*	*Sugar-cane*
March 4, 1935	754	788	744	April 1	958	963	828
April 29	379	308	366	June 24	1,072	1,533	1,394
June 24	880	1,299	976	Sept. 16	1,650	3,021	2,639
Aug. 19	976	1,420	1,037	Dec. 9	1,231	1,902	1,084
Oct. 14	1,724	2,540	1,226				
Dec. 9	732	1,219	526				
Totals	5,445	7,574	4,875	Totals	9114,	7,419	5,945
Treatment means	680·6	946·7	609·4	Treatment means	613·9	927·4	743·1

Variety means		*Rotation means*	
Guatemala Grass	937·1	8-week rotation	745·6
Sugar-cane	676·1	12 ,, ,,	761·5
Para Grass	647·2		

Statistical analysis showed a significant difference between the variety yields, but no significance for the rotation treatment or the interaction of rotation and variety. The variety yields, in tons per acre, were:

Guatemala Grass, $23{\cdot}85 \pm 0{\cdot}835$; Sugar-cane, $17{\cdot}21 \pm 0{\cdot}835$; Para Grass, $16{\cdot}50 \pm 0{\cdot}835$.

Therefore, the Guatemala Grass gave a higher yield than the other two varieties, but the yields of Sugar-cane and Para Grass are not significantly different.

Previous results indicate that the composition and nutritive quality of these three varieties are notably dissimilar. For herbage of three months' maturity, the following analytical data have been recorded [3]:

Variety	*Dry matter, per cent.*	*Crude protein in dry matter, per cent.*	*Crude protein in herbage, per cent.*	*Relative nutritive value*
Guatemala Grass	16·45	5·74	0·94	100
Sugar-cane (Uba)	16·64	4·25	0·71	75
Para Grass	17·42	6·87	1·20	128

Co-ordinating these analytical data with the varietal yields already quoted, the respective yields of crude protein per acre for Para Grass and Sugar-cane are 89 and 54 per cent. of that of Guatemala Grass. Crude-protein percentage provides a rough index of nutritive quality, and these figures indicate that the poor quality combined with low potential yield of Sugar-cane makes it quite inferior to either of the other two species as a cultivated fodder crop. In contrast, the good quality of the Para Grass largely compensates for its relatively low yield.

In evaluating these data for yields of herbage and nutrient, the soil type on which the experiment was located must be considered. The College Farm lies on the dividing line between the sandy schist soils of the Northern Range and the heavy alluvial loams and clays of the Central Plain. The soil is a sandy or gravelly loam, naturally acidic, and not rich in plant-foods. The above conclusions—and others to follow—based on accurate yield-comparisons between varieties apply primarily to this soil type. For example, it is almost certain that Para Grass would do relatively better on the heavier, more humid soils of the Central Plain. On the other hand, findings of a more general character derived from major quality differences, or from the response of the grasses as a whole to the environment, are of much wider application.

2. Propagation of Para Grass

After the last harvest on Dec. 9 the weeds on each plot were mown and weighed. Statistical analysis of the data showed that the weed-growth on the plots of Para Grass was significantly less than that on the cane plots, but greater than that on the Guatemala Grass plots. This demonstrates that as smother crops, the varieties can be arranged in the order: (1) Guatemala Grass, (2) Para Grass, (3) Sugar-cane. From its habit of growth [3] Para Grass ought to be at least as efficient as Guatemala Grass in suppressing weeds; in this experiment its relative inefficiency was traced to the poor development of the individual stools. On the $3 \times 1\frac{1}{2}$ ft. spacing adopted, much inter-stool space was left exposed after each harvest, thereby encouraging weed establishment and growth. On the other hand, the stools in Guatemala Grass developed satisfactorily, so that the adjacent ones were practically touching. The runners in the Para Grass had not rooted as freely as was expected, and it was thought that the method of propagating this species from rooted sections of old stools, as used in the experiment, could be greatly improved. It was

therefore decided to carry out a comparative test of the following methods of propagating Para Grass.

(1) Rooted sections planted 2 × 1 ft.

(2) Uncut stolons: (*a*) broadcast on surface; (*b*) in drills 2 ft. apart and 1 in. deep, and covered with soil; (*c*) in drills 2 ft. apart and 4 in. deep and covered with soil.

(3) Stolon cuttings 3–6 in. long: (*a*) Broadcast on surface; (*b*) in drills 2 ft. apart and 1 in. deep, and covered with soil; (*c*) in drills 2 ft. apart and 4 in. deep, and covered with soil.

Observations continuing for three months showed that uncut runners are both easier to plant and more efficacious than either cuttings or rooted sections. Surface broadcasting of the cuttings or stolons gives a fair percentage of 'takes', but does not ensure close enough contact with the soil; the ultimate stand tends to be patchy and difficult to weed. Planting either cuttings or stolons 4 in. below the surface was a partial failure. Planting from rooted sections gave a high percentage of successes, but is expensive and laborious, and is slow in producing a thick stand unless a very close spacing is adopted. Planting runners in shallow drills 1–2 in. in depth, and subsequently covering lightly with soil, produces rapid and satisfactory sprouting.

From these results the following technique for the propagation of Para Grass has been evolved and has proved highly successful. Uncut stolons are collected from any available source and placed by hand, in a continuous line of two to three runners, in very shallow drills 2 ft. apart. The field is then rolled or boarded over with a light planker so as to bring the runners into close contact with the soil moisture and cover them to a depth of about 1 in. One or two weedings are advisable in the first eight weeks, but sprouting is rapid, and the rows are close enough for the crop ultimately to establish and maintain a thick cover over the whole area.

3. Elephant Grass (*Pennisetum purpureum* Schumach)

It has been shown [2, 3] that Elephant Grass has many of the essential requisites of a good perennial fodder grass. In Trinidad it is unfortunately susceptible to sporadic but severe attacks of *Helminthosporium* spp., which may devastate the crop in years when climatic conditions favour the fungus. As the disease is not reported in epidemic form in other tropical colonies, and only occurs sporadically in Trinidad, it seems probable that some of the many varieties or strains of Elephant Grass may be immune or highly resistant to *Helminthosporium* attack. In the 1934 crop of Elephant Grass [2], which was heavily infected, one stool was discovered absolutely free from *Helminthosporium* spotting, and standing out in a green healthy condition in the middle of a patch of brown and wilted vegetation. As it might have been a sport which had developed a degree of resistance to the fungus, produce from this stool was used for its rapid vegetative multiplication by rooted sections. On the advice of the Professor of Mycology, in Aug. 1935, a checker-board, involving 32 plots and 16 stools in each, was laid out on the College Farm to test the intensity of infection occurring in the selected strain, as com-

pared with that found on plants propagated from ordinary bulk produce. For ease of description, the two types of planting material will be termed, respectively, 'A. Resistant' and 'B. Susceptible'. The cultural practice was maintained at a high standard. In Feb. 1936, six months after planting, in order to determine the intensity of the infection with *Helminthosporium* spp., a census of the plots was made by three independent observers, whose findings tallied very closely, the average results being:

	Intensity of infection			
	Free	*Slightly infected*	*Infected*	*Heavily infected*
A. Resistant . . .	7	7	2	0
B. Susceptible . .	1	3	2	10

The test of independence applied to these data gives a χ^2 value of 16·1, proving a significant difference in intensity of infection between the two types of planting material, A and B. To provide further evidence, the experiment was continued for another six months, and a count was then taken of the number of stools surviving in each plot. Out of a possible total of sixteen stools per plot, the mean values recorded were:

	Stool survival per plot
A. Resistant	15·81
B. Susceptible	11·62

The mean difference of 4·19 in favour of the resistant strain is significant at the 1 per cent. point.

These tests indicate that, although the A selection is not immune to *Helminthosporium* attack, it has shown more resistance to the fungus than the bulk crop of Elephant Grass. As no serious outbreak of the fungus has occurred in the last two years, the experiment has remained in abeyance. Spotting of the leaves has been noted occasionally, showing that the fungus is still sporulating, but is not apparently injuring the Elephant Grass crop, which was particularly luxuriant throughout 1937.

This partial disappearance of the *Helminthosporium* fungus has also precluded testing the resistance of a new strain of Elephant Grass, imported from Uganda in 1935. The disease is said to occur on the grass grown in Uganda, but not in epidemic form, and possibly the newly introduced strain is more resistant than the original importation. Botanically, the new strain differs from the old in its finer, less fibrous culms, narrow, rather transparent leaves, and much more luxuriant foliage. Its leafiness suggests that the nutritive quality of the roughage might be particularly good.

4. The 1936–7 Experiment

In the light of these results, a more comprehensive experiment was begun in 1936. Six randomized blocks were used and the following treatments were included:

Varieties: Guatemala Grass, Elephant Grass, Para Grass.

Spacing: A. $3 \times 1\frac{1}{2}$ ft. B. $2 \times 1\frac{1}{2}$ ft.

Harvesting Height: Low, 3 in. above, and High 12 in. above ground-level.

A factorial design for the variety and spacing treatments was used with the other two treatments introduced on half-plots. Excluding the borders, the whole-plot size was 24×45 ft. or 1/40 acre approximately. Before planting, a green manure crop of sunn hemp (*Crotalaria juncea*) was grown on the experimental site and ploughed under along with 5 tons of farmyard manure per acre. To maintain the fertility of the soil throughout the experiment, 1 cwt. per acre of a complete fertilizer was applied every two months, i.e. at the end of each harvest. The fertilizer was a mixture of sulphate of ammonia, superphosphate, and muriate of potash in the ratio 2 : 2 : 1 by weight. These regular post-harvest manurial dressings, it is thought, enable comparable herbage samples to be taken for chemical analysis at the different seasons covered by the experimental period.

The grasses were planted between June 18 and 20, 1936, just after the wet season had set in (the best time for the establishment of perennial fodder grass crops in Trinidad). The propagation of the Guatemala Grass and the Elephant Grass was from rooted sections of old stools, each section having two to three tillers so as to ensure a high percentage of 'takes'. The sets of the Elephant Grass were obtained from the strain that had shown resistance to *Helminthosporium* spp. (Section 3). Propagation of the Para Grass was from stolons, by the improved method already described. The sprouting of the Elephant Grass and the Para Grass was both rapid and complete, less than 5 per cent. of supplies being required when the blanks were filled up in the middle of July. The Guatemala Grass not only sprouted much more slowly than the other two species, but some 25–30 per cent. of the sets rotted, necessitating copious supplying. These supplies rooted satisfactorily, and in three months from planting a stand of approximately 100 per cent. was recorded for all three varieties. During that time, the plots were hand-hoed and weeded twice, and at the first harvest on Sept. 28 the soil over the whole area was in excellent condition and free from visible weeds. No further cultivation was given while the experiment lasted. Herbage yields from this initial harvest were not included in the experimental results, but the actual yield-trial began then and continued until Oct. 25, 1937, a period covering a full calendar year and including, on an eight-week cutting-rotation, seven harvests from each plot.

The weather during the second half of this period was abnormal and, in view of the influence of season on experimental results, to be referred to later, the rainfall data are given in Table 2. Briefly, the wet season of 1937—as bracketed in the table—was characterized by relatively low rainfall and humidity, and high temperatures, whilst in Dec. 1937 and Jan. 1938, when the dry season usually begins, the direct converse occurred.

The plots of the three varieties were quite distinct, particularly just before harvest, when the different habit of growth of the grasses was most apparent. On the average, at eight-weeks' maturity, the Elephant Grass attained a height of 6–8 ft., as compared with 4–5 ft. for the Guatemala Grass and 3–4 ft. for the Para Grass. The Elephant Grass showed marked culm or cane development, practically free of leaves for

about 3–4 ft. above ground-level, as distinct from the Guatemala Grass herbage which was very leafy and had little stem. The Para Grass was quite different from either, consisting of a tangled mass of herbage comprising semi-upright leafy shoots and long prostrate runners with little foliage development. The two-months' cutting-rotation was

TABLE 2. *Monthly Rainfall in Inches at the Imperial College of Tropical Agriculture, Trinidad, for the Years 1932–37.*

	1937		Average for previous five years 1932–36	
Jan.	6·21		2·84	
Feb.	0·81		1·09	
March	0·64		1·92	
April	2·91		1·60	
May	0·47		6·15	
June	6·36		8·36	
July	4·54	21·74	8·34	43·03
August	5·66		10·59	
Sept.	4·71		9·59	
Oct.	6·30		6·81	
Nov.	11·38		8·80	
Dec.	8·64		7·19	
Total	58·63		73·19	

selected as that most likely to fulfil the average requirements of the three grasses: it is possibly on the short side for Guatemala Grass and on the long side for Elephant and Para Grass. This should not affect the experimental results, as considerable latitude in the length of the period between harvests is allowable without affecting the treatment comparisons.

5. YIELD OF HERBAGE

TABLE 3. *Yield of Herbage for the Individual Harvests (Total yield in lb. from six sub-plots)*

Date	Guatemala Grass				Elephant Grass				Para Grass				Harvest Totals
	High		Low		High		Low		High		Low		
	A	B	A	B	A	B	A	B	A	B	A	B	
Nov. 23, 1936	1,500	1,412	887	888	2,614	2,755	2,668	2,867	1,326	1,274	1,527	1,258	20,976
Jan. 18, 1937	1,404	1,222	1,075	1,098	1,542	1,795	1,799	1,934	1,294	1,205	1,343	1,034	16,745
March 16, 1937	767	740	571	630	696	760	952	979	701	633	856	722	9,007
May 10, 1937	502	530	454	483	737	725	796	680	470	417	702	528	7,024
July 5, 1937	873	859	623	731	1,374	1,401	1,337	1,279	509	491	842	629	10,948
Aug. 30, 1937	1,210	1,078	851	827	1,602	1,785	1,463	1,535	837	835	1,041	824	13,888
Oct. 25, 1937	1,057	1,040	862	902	1,441	1,635	1,435	1,617	985	897	1,108	946	13,925
Treatment Totals	7,313	6,881	5,323	5,559	10,006	10,856	10,450	10,891	6,122	5,752	7,419	5,941	92,513
Height Totals	14,194		10,882		20,862		21,341		11,874		13,360		
Variety Totals	25,076				42,203				25,234				

The analysis of variance of these herbage yields proved that the variety and the interaction between the variety and height of cutting were the only treatment effects that had a significant influence on the results. The

former was significant at the 1 per cent. point and the latter at the 5 per cent. point. The yields expressed in tons per acre were:

	High-cut	*Low-cut*	*Variety mean*
Guatemala Grass . .	42·40±2·859	32·52±2·859	37·46±1·995
Elephant Grass . .	62·35 ,,	63·78 ,,	63·06 ,,
Para Grass . . .	35·48 ,,	39·93 ,,	37·71 ,,

The Elephant Grass, at either level of cutting, gives a better yield of herbage than the other varieties. Cutting the Guatemala Grass about 1 ft. above ground-level has produced a significant increase in the yield of herbage. The difference in height of cutting has not altered significantly the yield of the other two varieties.

The difference in spacing has had apparently no effect on the potential yield of any of the varieties. In the wide-spaced plots the increase in the size of the individual stools easily compensates for the smaller stool population, and evidently considerable latitude in the spacing may safely be used up to about 3×2 ft. per plant. The close-spaced plots of the Guatemala Grass—$2 \times 1\frac{1}{2}$ ft.—showed, throughout the experimental period, a much smaller weed-growth than the wide-spaced plots, and for this grass, provided planting material is plentiful, the closer spacing is advocated. For the other two varieties the difference was not so obvious and the wider spacing might be preferable, as it would mean an appreciable saving in the number of sets and in the labour required to plant up a new area.

6. Content of Dry Matter

At every harvest samples of the herbage from each variety at each height of cutting were analysed chemically. As the difference in spacing was held to have little influence on the composition of the herbage, no attempt was made to obtain separate samples for the A and B spacings. The non-significant effect of spacing on yield indicates that this assumption was justifiable. The samples in each case were taken from a bulk-sample made up of the herbage from three stools from each plot; otherwise the sampling technique was as described in [2]. Duplicate samples, each of 1 kg., were taken on every occasion, and, by kind favour of Prof. F. Hardy, were analysed separately in the Chemistry Department of the Imperial College.

As the sampling and chemical analyses were duplicated it was possible to compare statistically these data using the within-duplicate variance as the estimate of experimental error. The most obvious feature is the marked difference in the dry-matter content of the three grasses, as shown by the mean values for the experimental period: Para Grass, 24·66; Guatemala Grass, 19·34; and Elephant Grass, 15·58 per cent.

These mean values are significantly different at the 1 per cent. point. For green herbage the Para Grass is unusually rich in dry matter and, even if the composition of the dry matter is only of average quality, this grass apparently has a higher nutrient value, weight for weight, than either of the other two grasses. The Elephant Grass is a very succulent type of fodder; on the soilage system, this is not altogether desirable,

because it involves a greater quantity of roughage being handled daily to make up the maintenance ration.

The interaction variance for variety by height of cutting is also significant. Comparison of the relative mean values showed that there was no difference in dry-matter percentage between the high-cut and low-cut Elephant Grass. High-cutting of the Para Grass and low-cutting of the Guatemala Grass produced a significant decrease in the dry-matter percentage of the produce. On general principles, one would expect that the high-cut herbage, on account of its more leafy nature,

TABLE 4. *Dry Matter as Percentage of Green Herbage (Mean values from duplicate analyses)*

Date of harvest	*Elephant Grass*		*Guatemala Grass*		*Para Grass*		*Mean value for each harvest*
	High	*Low*	*High*	*Low*	*High*	*Low*	
Nov. 23, 1936	12·50	11·65	15·81	14·80	21·58	20·99	16·22
Jan. 18, 1937	13·10	12·80	16·97	16·16	24·25	24·88	18·03
March 16, 1937	18·44	20·79	24·84	23·46	26·83	28·55	23·82
May 10, 1937	20·07	19·28	27·69	25·67	31·58	32·65	26·19
July 5, 1937	16·10	16·20	19·20	16·52	22·05	23·22	18·88
Aug. 30, 1937	13·55	13·65	18·64	16·67	20·75	21·60	17·48
Oct. 25, 1937	14·39	15·44	18·29	15·99	22·54	23·72	18·34
Treatment means	15·45	15·71	20·21	18·47	24·23	25·09	
Variety means	15·58		19·34		24·66		

would contain more moisture, and this was found to be true for the Para Grass. With Elephant Grass, the growth on all the plots has attained sufficient maturity to mask the influence of the cutting-height. With the Guatemala Grass, high-cutting induced more rapid sprouting, a significantly higher yield, and, in consequence, a more mature type of herbage at harvest time. It is this additional maturity that causes the unexpectedly good dry-matter content of the high-cut produce. Incidentally, this provides another link in the evidence that high-cutting of Guatemala Grass does encourage greater productivity.

There was also a very marked and significant seasonal change in the dry-matter content of all the grasses. In Trinidad the seasonal effect on crop-growth is closely correlated with the monthly rainfall [1, 2], and the dry-matter percentages all show the expected negative correlation with the number of inches of rain since the preceding harvest. The seasonal effect is responsible for a change in dry matter lying between ± 20 and ± 30 per cent. of the mean percentage of each grass. This indicates that there must be a considerable variation from month to month in the total nutrient content in a given weight of green herbage.

7. CONTENT OF CRUDE PROTEIN

The summary of the crude-protein analyses given in Table 5 leads to the following conclusions which are supported by statistical proofs derived from the full data. Assuming that crude-protein content is a reasonable index of nutritive value, there appears to be little difference

in the quality of the dry matter in the three grasses. On the average for the whole period Para Grass is slightly inferior to the other two. This inferiority is due to an acute drop in the protein percentage in the dry months of the year; in a wet season the percentage is equal to, or higher than, that of the other two grasses (Fig. 1). High-cutting does produce a small but fairly consistent increase in the amount of protein in the dry matter of all three grasses.

TABLE 5. *Crude-Protein Content of the Dry Matter and Green Herbage*

	Crude protein in dry matter (per cent.)							*Crude protein in green herbage (per cent.)*						
	Elephant Grass		*Guatemala Grass*		*Para Grass*		*Mean value for each harvest*	*Elephant Grass*		*Guatemala Grass*		*Para Grass*		*Mean value for each harvest*
Date of harvest	*High*	*Low*	*High*	*Low*	*High*	*Low*		*High*	*Low*	*High*	*Low*	*High*	*Low*	
Nov. 23, 1936	7·07	6·91	7·36	7·28	8·07	7·64	7·39	0·88	0·80	1·16	1·07	1·74	1·60	1·21
Jan. 18, 1937	7·73	6·98	7·37	7·25	6·67	6·09	7·01	1·01	0·89	1·25	1·17	1·62	1·51	1·24
March 16, 1937	6·70	5·98	6·32	6·12	5·78	5·41	6·05	1·23	1·24	1·57	1·43	1·55	1·54	1·43
May 10, 1937	6·75	6·85	6·79	6·77	5·55	5·17	6·31	1·35	1·33	1·88	1·73	1·75	1·69	1·62
July 5, 1937	6·99	6·58	7·12	7·53	5·72	5·75	6·61	1·13	1·06	1·36	1·24	1·26	1·33	1·23
Aug. 30, 1937	7·04	6·60	7·04	6·35	6·50	5·98	6·58	0·95	0·90	1·31	1·06	1·35	1·29	1·14
Oct. 25, 1937	7·10	6·89	7·22	6·67	6·66	6·44	6·83	1·02	1·07	1·32	1·07	1·50	1·52	1·25
Treatment means	7·05	6·68	7·03	6·85	6·42	6·07		1·08	1·04	1·41	1·25	1·54	1·50	
Variety means	6·86		6·94		6·24			1·06		1·33		1·52		

The relationship between percentage of crude protein in the dry matter and rainfall is somewhat complex. In dry seasons the percentage drops distinctly [2] until the rains set in, when it tends to rise again (Table 5). In prolonged wet seasons, however, the rate of growth of the plant is greatly accelerated, and, with a fixed cutting-rotation, the herbage is more mature at harvest. If this additional maturity is sufficiently marked, the protein percentage may fall again at the height of the wet season [1]. The percentage of crude protein is evidently balanced delicately between the rainfall and maturity factors. In this experiment the rainfall during the wet season was markedly subnormal, and only the first two stages of the process are apparent, viz., a positive correlation between rainfall and protein-content. This means that in the dry season the nutritive quality of the dry matter is low. In practice this feature is more than offset by the proportionately greater rise in the percentage of dry matter at the same season of the year.

The second half of Table 5, recording the crude-protein content as a percentage of fresh fodder, is of more practical significance, as these data indicate the nutritive quality of the different types of herbage. The three grasses show very marked differences in quality, and the height of cutting has also had an appreciable effect on the percentage of crude protein. The comparable figures are:

	Crude protein as per cent. of green herbage		
	High-cut	*Low-cut*	*Variety mean*
Para Grass . . .	1·539	1·497	1·518
Guatemala Grass . .	1·407	1·253	1·330
Elephant Grass . .	1·081	1·041	1·061
Mean, for cutting-height .	1·342	1·264	. .

Significant difference, 0·05.

Para Grass is thus the best grass and Elephant Grass the poorest grass, but on the average high-cutting has produced a slight improvement

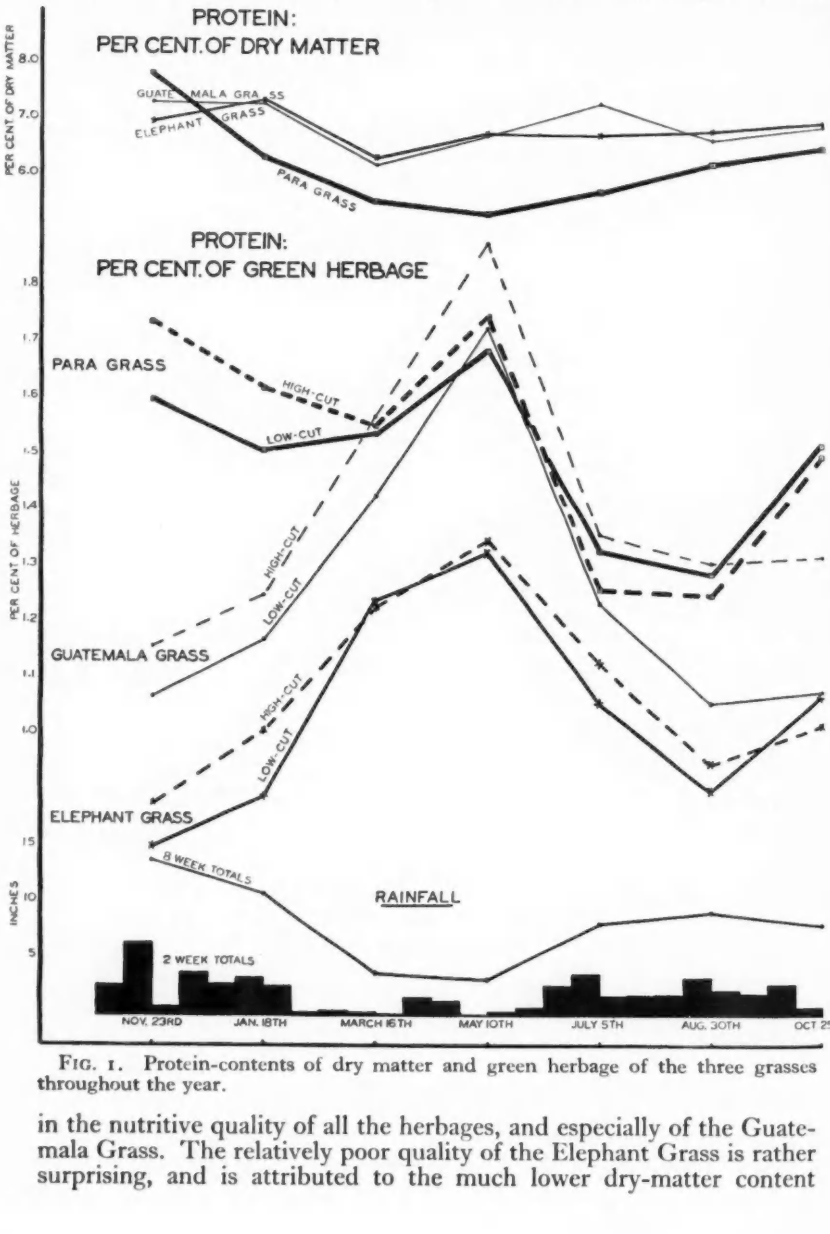

FIG. 1. Protein-contents of dry matter and green herbage of the three grasses throughout the year.

in the nutritive quality of all the herbages, and especially of the Guatemala Grass. The relatively poor quality of the Elephant Grass is rather surprising, and is attributed to the much lower dry-matter content

combined with greater maturity at the time of harvest. The significant increase in the percentage of crude protein in the herbage in the dry season is due to the increase in dry-matter percentage, as the quality of the dry matter is actually worse in periods of low rainfall (Fig. 1).

8. Yields of Dry Matter and Crude Protein

Cropping quality is much better indicated by yields of dry matter and crude protein than by gross weight of herbage. The analytical data have therefore been used to calculate the total yield of dry matter and of crude protein for each treatment and each harvest. A statistical examination of the resultant data provides a clear picture of the relative merits of the various treatments. For dry matter the comparable annual yields are:

	Dry matter (tons per acre per annum)		
	High-cut	*Low-cut*	*Variety mean*
Elephant Grass . .	18·02	18·62	18·32
Para Grass . . .	16·70	19·47	18·09
Guatemala Grass . .	16·18	11·48	13·83

Significant difference, 2·85 tons.

The Guatemala Grass is much inferior to the other two varieties in yield of dry matter. The very poor yield of Guatemala Grass in the low-cut series is largely responsible for this inferiority, the high-cut series being little, if any, worse than the other treatments. Low-cutting of the Para Grass just fails to be significantly better than high-cutting.

Similarly calculated, the yields of crude protein were:

	High-cut (lb. per acre per annum)	*Per cent. of mean*	*Low-cut (lb. per acre per annum)*	*Per cent. of mean*
Elephant Grass . .	1,431	113·5	1,398	110·8
Para Grass . . .	1,241	98·5	1,342	106·4
Guatemala Grass . .	1,278	101·2	878	69·6

By this test, also, the low-cut Guatemala Grass gave much the poorest yield; otherwise there are no striking differences between the various treatments. The Elephant Grass, irrespective of height of cutting, is slightly better than either of the other two varieties. It is possible that low-cutting of Para Grass is the better harvesting practice. This requires further proof as the 8 per cent. difference reached in this experiment is not quite significant.

9. Proximate Composition

As an additional test of the nutritive quality of the different types of herbage, a complete analysis was made of the proximate constituents of the samples collected on May 10 and August 30. These samples were chosen as representative of the quality of the herbage in the height of the dry season and in the middle of the wet season. The mean values for the duplicate analyses are tabulated in Table 6.

There are no striking differences in the average composition of the

dry matter. The Elephant Grass is slightly the best of the three, being relatively rich in crude protein and ash, and low in crude fibre. The Para Grass has a higher carbon-nitrogen ratio than the other two, especially in the dry season, when the protein percentage is particularly low.

TABLE 6. *Proximate Analyses of the Three Grasses*

Constituent	Sample	Elephant Grass			Guatemala Grass			Para Grass		
		High	*Low*	*Mean*	*High*	*Low*	*Mean*	*High*	*Low*	*Mean*
		Percentage of oven-dry material								
Dry matter	May	20·02	19·48	19·75	27·69	25·67	26·68	31·58	32·65	32·11
	Aug.	13·55	13·65	13·60	18·64	16·67	17·65	20·75	21·60	21·17
	Mean	16·78	16·56	*16·67*	23·16	21·17	*22·16*	26·16	27·12	*26·64*
Crude protein	May	6·75	6·85	6·80	6·79	6·77	6·78	5·55	5·17	5·36
	Aug.	7·04	6·60	6·82	7·04	6·35	6·69	6·50	5·98	6·24
	Mean	6·89	6·72	*6·81*	6·91	6·56	*6·73*	6·02	5·57	*5·80*
Crude fibre	May	34·15	33·92	34·03	33·57	32·97	33·27	32·15	34·20	33·17
	Aug.	33·52	32·80	33·16	34·72	35·67	35·19	33·90	35·37	34·63
	Mean	33·83	33·36	*33·59*	34·14	34·32	*34·23*	33·02	34·78	*33·90*
Carbohydrate (+Ether-extract)	May	46·77	46·80	46·78	50·90	50·92	50·91	53·34	51·50	52·42
	Aug.	42·49	43·08	42·78	45·37	43·83	44·60	47·37	47·09	47·23
	Mean	44·63	44·94	*44·78*	48·13	47·37	*47·75*	50·35	49·29	*49·82*
Total ash	May	12·32	12·43	12·37	8·74	9·33	9·03	8·95	9·12	9·03
	Aug.	16·94	17·51	17·22	12·86	14·14	13·50	12·21	11·55	11·88
	Mean	14·63	14·97	*14·80*	10·80	11·73	*11·26*	10·58	10·33	*10·45*

TABLE 7. *Analyses of the Ash of the Three Grasses*

Constituent	Sample	Elephant Grass			Guatemala Grass			Para Grass		
		High	*Low*	*Mean*	*High*	*Low*	*Mean*	*High*	*Low*	*Mean*
		Percentage of oven-dry material								
Total ash	May	12·32	12·43	12·37	8·74	9·33	9·03	8·95	9·12	9·03
	Aug.	16·94	17·51	17·22	12·86	14·14	13·50	12·21	11·55	11·88
	Mean	14·63	14·97	14·80	10·80	11·73	11·26	10·58	10·33	10·45
CaO	May	0·925	0·943	0·934	0·506	0·486	0·496	0·727	0·706	0·716
	Aug.	0·848	0·862	0·855	0·315	0·523	0·419	0·654	0·622	0·638
	Mean	0·886	0·902	0·894	0·410	0·504	0·457	0·690	0·664	0·677
P_2O_5	May	0·910	1·037	0·973	0·687	0·773	0·730	0·748	0·780	0·764
	Aug.	1·235	1·407	1·321	0·841	0·978	0·909	1·002	0·981	0·991
	Mean	1·072	1·222	1·147	0·764	0·875	0·819	0·875	0·880	0·877
Na_2O	May	0·040	0·028	0·034	0·037	0·028	0·032	0·215	0·191	0·203
	Aug.	0·042	0·044	0·043	0·032	0·020	0·026	0·281	0·328	0·304
	Mean	0·041	0·036	0·038	0·034	0·024	0·029	0·248	0·259	0·253
Cl	May	1·020	1·074	1·047	0·938	1·075	1·006	0·918	0·840	0·879
	Aug.	1·270	1·214	1·242	1·075	1·484	1·279	1·230	1·199	1·214
	Mean	1·145	1·144	1·144	1·006	1·279	1·142	1·074	1·019	1·046
SiO_2-free ash	May	7·67	7·61	7·64	5·16	5·75	5·45	6·24	6·14	6·19
	Aug.	9·77	9·77	9·77	5·70	6·81	6·25	7·75	7·69	7·72
	Mean	8·72	8·69	8·70	5·43	6·28	5·85	6·99	6·91	6·95

The height of cutting and the seasonal factors are also responsible for certain differences in the composition of the dry matter. High-cutting tends to improve slightly the quality of the herbage, particularly its crude-protein content. The greatest response to season is in the percentage of dry matter, as already discussed, but there is also a definite,

if less marked, change in its quality. During the wet season there is an increase in the crude protein and mineral constituents of the dry matter, and a definite drop in the percentage of carbohydrates and fats. The change in crude-protein percentage is particularly marked with the Para Grass, which shows very poor leaf-development in the dry season. As already stated (page 327), the summer rainfall during 1937 was sub-normal, and the seasonal responses were therefore not as marked as those recorded in some of the previous experiments.

10. Minerals

The mid-season samples of the produce obtained in dry and wet weather were also used for determining the important mineral constituents of the ash, the mean composition of which is compared below with that from good cultivated pasture in Great Britain [5].

	Trinidad fodder crop	*Cultivated English pasture*
	Percentage of dry matter	
Total ash	12·17	9·787
CaO	0·676	1·004
P_2O_5	0·948	0·735
Na_2O	0·107	0·246
Cl	1·111	0·950
N	1·035	2·825
SiO_2-free ash	7·17	6·637

The mineral composition of good pasture approximates to that of cow's milk, the recognized standard of a well-balanced foodstuff. On this basis the average cultivated fodder crop in Trinidad, at eight weeks' maturity, contains ample chloride, phosphate, and total ash-constituents, but is rather low in calcium and sodium, and, of course, in nitrogen. It is not seriously deficient in any of the major mineral requirements of a fodder crop.

There are also notable differences in the mineral composition of the three grasses. Elephant Grass is the best, being much the highest in ash-content and appreciably below English pasture only in the percentage of Na_2O. Chloride and phosphoric acid are ample in all three grasses, but the Guatemala Grass and the Para Grass are distinctly low in CaO, especially the former. The Para Grass is exceptional in containing the full Na_2O requirement, but the other two species are too low in this constituent.

The seasonal response is perfectly clear. In the wet season the percentage of all the minerals increases, except that of the CaO, which drops. This is in complete agreement with the results already recorded for crops of temperate regions [5, 6]. The effect of height of cutting on the mineral composition is not too obvious: in general, the high-cut Para Grass is richest and the low-cut Elephant Grass and Guatemala Grass are poorest in minerals. The mineral differences in the produce obtained from those two systems of harvesting are not sufficiently marked to be of much practical significance.

11. Effect of Manuring on the Quality of the Herbage

The experiment was conducted on cultivated land which had been cropped and manured consistently for several years. The experimental crop was given regular dressings of a complete fertilizer. To ascertain whether the composition of the herbage was widely different from that grown on unfertilized soil, an adjacent area of pasture on the same soil type was ploughed and planted up with small plots of the three grasses when the experiment was started. This area had been under Savannah Grass (*Axonopus compressus*) pasture for at least ten years, and, apart from the dung voided by the grazing stock, had not been manured. The fodder-grass plots established there were cultivated and harvested along with those of the main experiment, but were given no fertilizer. Observations showed that the grasses on the unfertilized plots grew quite satisfactorily, but not so luxuriantly as those on the adjacent cultivated land: the yield was below that from the manured series, and the herbage when cut was shorter, more leafy, and less mature. On Aug. 30, 1937, at the end of a year's cropping, samples of the produce were analysed, and the results are tabulated in Table 8, along with the corresponding figures from the main experiment.

Table 8. *Composition of Herbage from Manured and Unmanured Land*

	Elephant Grass		*Guatemala Grass*		*Para Grass*	
	Manured	*No manure*	*Manured*	*No manure*	*Manured*	*No manure*
Dry matter	13·55	13·20	18·64	18·40	20·75	20·10
	Percentage of oven-dry material					
Crude protein	7·04	9·16	7·04	8·30	6·50	9·04
Crude fibre	33·52	29·37	34·72	34·05	33·90	33·40
Carbohydrate (+Ether-extract)	42·50	43·02	45·38	45·79	47·38	46·94
Total ash	16·94	18·45	12·86	11·86	12·22	10·62
CaO	0·848	0·860	0·315	0·440	0·654	0·650
Na_2O	0·042	0·138	0·032	0·056	0·281	0·370
P_2O_5	1·235	1·460	0·841	0·840	1·002	0·940
Cl	1·270	0·660	1·075	1·170	1·230	0·750
SiO_2-free ash.	9·77	10·17	5·70	5·81	7·75	7·21

The outstanding feature of these results is that the produce from the unmanured land is, in general, of better quality than that from the cultivated area. The explanation of this apparent paradox seems to lie in the difference in maturity of the two types of herbage, that from the unmanured plots being much more backward. The consistently high protein, and the low dry matter and crude fibre lend strong support to this theory. Even in the ash analysis, with the possible exception of chloride, the produce from the non-fertilized soil compares favourably with that from the other series.

It is evident that good cultivation and adequate manurial treatment have greatly increased the productivity of these perennial tropical grasses. The good quality of the herbage from the unmanured land further

indicates that the Savannah Grass cover has prevented serious loss of fertility in the soil, for after a considerable period without manuring there is no marked deficiency. It is necessary to qualify this conclusion by stating that this particular pasture had not been heavily grazed, and the soil losses by utilization of the herbage were at a minimum.

12. Herbage Rations for Cattle

The analytical data have been used to estimate the quantity of each type of roughage that theoretically would suffice to fulfil the maintenance requirements of an average ox (1,000 lb. wt.). The estimates must be taken only as rough approximations to the true values, because of the great variability in the quality of the produce with any change in season, soil type, or harvesting technique. Further, accurate data recording the digestibility coefficients for tropical fodder crops and live stock are decidedly meagre. For herbage cut at the same stage of maturity, it has been shown [7] that the digestibility coefficient for each constituent, with the exception of the ether-extract, is approximately the same for similar fodder grasses. In tropical fodder grasses the percentage of fat relative to the other constituents is small, so that the variability of the ether-extract is of no great account. The digestibility percentages are of the order shown by average meadow grass grown in a temperate region.

Table 9. *Composition and Nutritive value of Herbage harvested in the Wet Season (Aug. 30, 1937)*

		Elephant Grass		*Guatemala Grass*		*Para Grass*	
Constituent	*Digestibility coefficient*	*Composition, per cent.*	*Quantity digested, per cent.*	*Composition, per cent.*	*Quantity digested, per cent.*	*Composition, per cent.*	*Quantity digested, per cent.*
Dry matter . .	..	13·60	..	17·65	..	21·17	..
Crude protein . .	67	0·93	0·62	1·24	0·83	1·33	0·89
Crude fibre . .	65	4·55	2·96	6·23	4·05	7·37	4·78
Carbohydrates . .	70	5·85	4·08	7·90	5·53	10·01	7·05
Starch equivalent per cent. (Gross digestible energy) . .	..	7·82		10·62		12·94	
Nutritive ratio . .	..	1:11·3		1:11·5		1:13·3	
Maintenance ration (6 lb. starch equivalent)	..	77 lb.		57 lb.		47 lb. Fresh herbage	

The figures for the Elephant Grass are in close agreement with those recorded in [8]. It is essential to note that the maintenance rations quoted are in all cases for produce cut at two months' maturity in the middle of the wet season. The rainfall in the experimental year was subnormal, and in a normal wet season the weight of roughage required for maintenance would be about 10 per cent. more than the figures recorded above. Similar calculations for samples collected in the height of the dry season showed that the quantity for each grass could be reduced by approximately 30 per cent. without any reduction in the total nutrient supplied. This fact is of practical importance as, in the dry weather, the productivity of the grasses is low and the total available bulk of roughage may consequently be limited. The maintenance values effectively illus-

trate the marked difference between the three grasses in the bulk of green produce necessary to provide a given quantity of nutrient. The weight of Guatemala Grass required is 21 per cent. and that of Elephant Grass 33 per cent. higher than that of the Para Grass. On the soilage system of feeding stock the two former species entail an appreciable increase in the cost of harvesting the herbage.

The nutritive ratios are wide but not excessively so. In the dry season they are rather worse, being respectively 1:12·2, 1:12·6, and 1:17·5. It might be advisable to increase slightly the proportion of protein in the concentrate ration to compensate for this drop of the protein in the roughage.

13. Discussion

All three grasses tested in this experiment are considered to be excellent perennial fodder crops as cultivated in Trinidad. They are all superior to Sugar-cane, the species most widely used for fodder production at present. The Para Grass is particularly attractive as it is healthy, hardy, easy to propagate, and combines good quality with fair yield. On the soilage system its high dry-matter percentage effectively reduces the bulk of green produce that has to be handled daily. It has the disadvantage of giving a poor, almost negligible, return during prolonged dry seasons, necessitating provision of some alternative form of roughage at such periods. It is particularly recommended for wet humid areas in which, provided reasonable drainage exists, its productivity will approach the maximum point. The risk of the dissemination of Para Grass on to arable land has already been discussed [3], and practical methods of avoiding it have been outlined.

The Elephant Grass gives the greatest yield of green matter, but it contains so much moisture that the yield of nutrient per acre is little better than that from the Para Grass; its succulence makes it very palatable to live stock. It grows very rapidly, and should be cut before the culms have begun to develop into pseudo-canes, or the stock is liable to pick out the leafy part of the ration and leave the rest uneaten. Roughage that has been allowed to get too mature should be chaffed. Elephant Grass thrives best on well-drained soils in areas of high rainfall. It has most of the essentials of an excellent fodder crop, and, in Trinidad, its only serious drawback has been its susceptibility to sporadic but severe attack by *Helminthosporium* spp. There is reason to believe that this difficulty has been partly overcome by the discovery of a more resistant strain than was originally used. During 1937 a detailed investigation of this fungal pest, kindly undertaken by the Mycological Department of the Imperial College, showed fairly conclusively the particular environmental conditions liable to cause an epidemic attack. The results will be published shortly, and should help materially towards the effective control of the disease.

The Guatemala Grass does not attain either the high yields of the Elephant Grass or the rich quality of the Para Grass. It holds an intermediate position in regard to productivity, dry-matter percentage, and nutritive value. Its chief recommendations are its general healthiness,

leafy character at almost any stage of maturity, relatively small seasonal variation, and longevity without cultural care or management. It has always been regarded as a crop that is particularly free from attack by fungal or other serious pests. To-day, this statement requires some qualification, by reason of the sudden appearance of a heavy infection of rust (*Puccinia polysora*)[1] on all the Guatemala Grass plots growing in the vicinity of the Imperial College, in Feb. 1938. This fungus has not previously been noted in Trinidad, but there are records of rusts appearing on Guatemala Grass in Virginia and Cuba. Their agricultural significance is not known. The current attack in Trinidad is sufficiently severe to cause at least a temporary reduction in the yield of fodder; its appearance is possibly due to the peculiar weather already noted, the high humidity in Dec. 1937 and Jan. 1938 being especially favourable to the spread of most fungal pests. At this stage it is impossible to forecast its future effect on the cropping quality of Guatemala Grass, but its development will be carefully observed.

The field practice for all these fodder grasses can be clearly defined. The spacing should be 3–5 sq. ft. per stool, 5 sq. ft. being preferable for Elephant Grass but 3 sq. ft. for Guatemala Grass, to help in weed-control. The Para Grass is best propagated in continuous rows at intervals of 2–3 ft. During the first three months after planting some inter-cultivation by hand or machine will be required to give the grasses a good start, and allow them to get the better of weed competition. After that, the crops should be able to thrive successfully without further cultural care for some considerable time. For high yields, regular manuring, particularly with nitrogen, is advocated.

The interval between harvests may range from 6 to 10 weeks. The shorter rotation is preferable for the Para Grass and the Elephant Grass, especially on fertile soil or where manuring is liberal [8]. The Guatemala Grass, being more leafy in its habit of growth, will probably do better on the longer rotation, and, at harvest, it is best to cut the culms about 1 ft. above ground-level, so as to encourage quick sprouting, high yield, and good quality. With Elephant Grass, high-cutting is also probably beneficial in improving slightly the quality of the fodder and being easier on the labourer. There are indications that low-cutting of Para Grass down to 3 in. above ground-level is the better practice. Shaving of the stools to the actual ground-level should be avoided [3]. After 6 to 9 months the high-cutting technique tends to cause a gradual accumulation of organic debris at the base of the stool, which must be removed from time to time by cutting back the stools to the 3-in. level once in every three to six harvests.

The nutritive values of the different grasses have been calculated, and the quantity required to supply a maintenance ration for cattle estimated. The ash analyses prove that none of the grasses is seriously deficient in any of the important mineral constituents. This is somewhat exceptional as, on the average, tropical fodder crops tend to be low in certain mineral ingredients. It demonstrates that, under cultivated conditions, it is possible to grow roughage with a mineral content

[1] Identified by Mr. R. E. D. Baker of the Department of Mycology, I.C.T.A.

adequate for maintenance; for production, it would be advisable to supplement the sodium and calcium constituents, as the percentage of these two elements in the roughage is rather low for young growing animals or milch cows.

The propagation, cultivation, and general management of perennial fodder crops grown in Trinidad can, therefore, be specified with fair accuracy. The time is now ripe to concentrate more on the plant-breeding side of this fodder-crop research in order to segregate the best strains from the available local material. This could be combined with the introduction of some of the more promising exotic species, as outlined in [5]. It is also essential to tackle the problem of pasture improvement and management, a new and extensive field for investigation of considerable practical importance. At present, Savannah Grass (*Axonopus compressus* Beauv.) is the only pasture species of any importance in Trinidad, and research would naturally begin with this grass. Climatically, Trinidad is apparently admirably suited for its cultivation, but the very variable and fluctuating condition of the existing pastures indicates that the problem is decidedly intricate. The research work for the immediate future is being organized in accordance with these ideas.

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THE EFFECT OF PRENATAL WEIGHT-CHANGES IN BREEDING SOWS ON THE NUMBER AND SIZE OF NEW-BORN PIGS

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Introduction.—Emphasis has often been placed on the importance of securing litters of heavy pigs at farrowing. It is justified by the knowledge that the mortality among small pigs is higher than among large. The latter are better able to fend for themselves and suckle more strongly, although litters with a high average weight at birth do not necessarily grow faster than those with a lower average weight. Yet there seems to be remarkably little information as to how such heavier pigs are to be produced; is it a matter of feeding or breeding, or merely chance? Large and small pigs do occur in the same litter, and litters may consist on the whole of light or heavy pigs. To judge from the appearance of breeding sows in general, breeders appear to differ concerning the optimum weight at which to keep them, and any investigation of this subject is likely soon to encounter individual differences among sows with respect to the tendency to put on weight. In sheep it is known that the weight of a lamb at birth is affected considerably by the weight of the ewe, although there are many cases in which a ewe in poor condition will produce a large lamb and vice versa [1]. To what extent does this apply to breeding sows? Records of the breeding stock at the Edinburgh University Farm, Shothead, taken at regular intervals, provide a partial answer to this question, though the main object of collecting the records was that of elucidating the more general problem of assessing the factors affecting the weight and growth of young pigs in order to determine the effects of heredity. In the present paper attention is directed mainly to determining the effect of varying weight-increases in the breeding sows on the weight of the pigs born, distinguishing the effect on the average weight of the litter from the effect on the variability within the litter. The reason for this is that at present it is widely believed that the variability of the pigs within a litter is due to environmental differences in the uterus, and the question arises whether or not the raising of the general level of the nutrition of the developing embryos will tend to diminish these differences. This is an indirect method of examining the hypothesis that the size of pigs at birth is conditioned by the degree of success in the competition for space or nutriment during gestation [2]. If, as will appear, there are large differences in the average weight of litters when the weight-increase of the sows has been the same, then some inherent differences in the sows with regard to the giving of nourishment will be indicated.

Material and Methods

The data have been obtained from monthly weighings of all breeding animals in a Large White herd, together with their weight at mating, before and after farrowing, and at weaning. The little pigs were weighed

damp as they were born. A certain amount of approximation has been made in the records of a few of the sows which either farrowed before they were expected to do so, and consequently missed the pre-farrowing weighing, or could not be weighed immediately after farrowing. The weight-changes in the sows followed, however, a fairly regular course, and such approximations are probably a smaller source of error than the necessarily single weighings. Further, the changes in sow-weight with which this paper is concerned are of such a size as to make the errors of

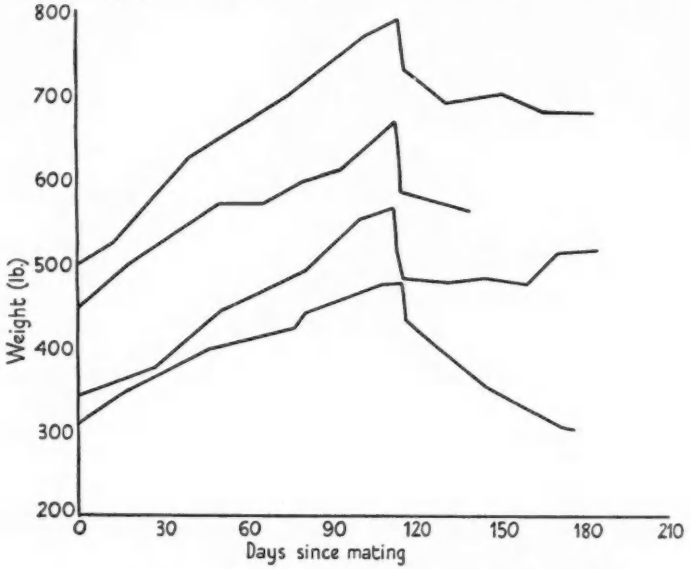


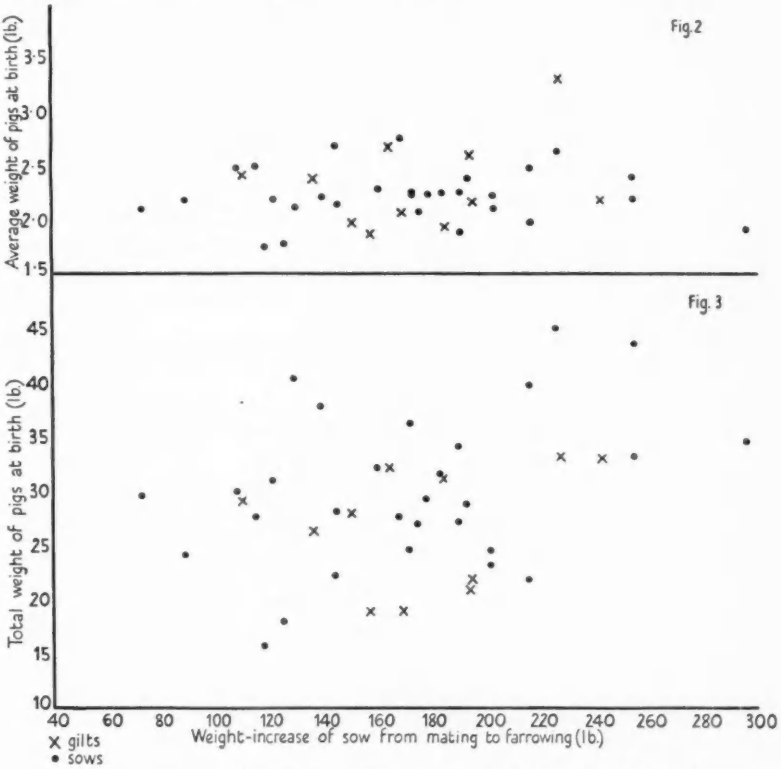
FIG. 1. Typical weight-changes in pregnant sows.

estimated or observed weight of comparatively slight significance. Three weight-increases of the sows have been considered: (1) that from mating to just before farrowing; (2) that during the month prior to farrowing (both (1) and (2) represent the weight-increase of the sow and her developing litter); and (3) the weight-increase from mating to just after farrowing, which may be said to represent the gain in weight of the sow herself during that period. The number of gestations involved is 40, and the number of sows 23.

In an effort to increase the birth-weights, liberal to excessive feeding was allowed. All animals were fed the same rations, but clearly did not get the same quantities. This is to be concluded partly from observations of communal behaviour, and partly from the considerable differences in the weight-increases. All the sows put on at least 50 lb. between mating and farrowing, so that the data to be presented do not deal directly with the effect of small increases or decreases. They are to be distinguished, therefore, from those which are concerned with rations of varying quality [3, 4, 5, 6], or of defective composition [7, 8].

Results

Typical weight-changes are shown in Fig. 1. The rate of increase appears to have been fairly regular throughout the gestation period. The amount by which a sow loses weight after farrowing is conditioned greatly by her appetite as well as by the actual weight of the pigs born, plus placenta, &c. Many sows ate very sparingly after farrowing and lost weight rapidly until normal appetite returned. The distribution of the sows according to weight-increase can be seen by reference to Figs. 2 and 3. The ranges of increases covered by reasonable numbers are 100–230 lb. for the period from mating to just before farrowing, and 30–70 lb. for the month prior to farrowing.



FIGS. 2 and 3. Distribution of sows according to weight-increase.

The average weights and numbers of animals are given in Table 1. It was intended at first to separate the gilts from the older sows, but the data did not justify the separation (see also Figs. 2 and 3); nor did it justify the assumption that an immature gilt would compete with her litter for nutriment, and therefore exhibit a different relation between

the increase in weight of the mother and the weight of the litter from that exhibited by older sows. Both groups put on the same average increase during pregnancy, and the litter weights (allowing for fertility differences) were approximately the same. The correlation between number of pigs born and average weight per pig yielded a coefficient of −0·51, which, under the circumstances, is reasonably close to Axelsson's figure of −0·406 (1928). On the basis of the regression coefficient associated with the former value, it can be shown that if the gilts had produced 13·5 pigs per litter instead of 11·1, the total litter-weight would have been very close to that observed for the sows.

TABLE 1. *Average Weights of Sows and their Litters (all weights in pounds)*

	Dams					*Litters*					
	Weight-increase			*Weight*							
	Mating to farrowing	*Sow* alone*	*Last month*	*Before farrowing*	*After farrowing*	*Total wt. of litter*	*No. of pigs*	*Av. wt. of pigs*	*Av. wt. at 3 weeks*	*Total wt. at 3 weeks*	*No. of pigs at 3 weeks*
Sows (30)	173	122	61	582	531	30·2	13·5	2·24	8·47	72·0	8·5
Gilts (10)	169	126	48	446	403	26·0	11·1	2·36	8·55	76·9	9·0
Sows and gilts (40)	172	123	58	548	498	29·1	12·9	2·27	8·44	73·2	8·6

* Equivalent to weight after farrowing less weight at mating.

Sows and gilts thus appeared to have had more than enough food for their own and their litters' needs, so that it was decided to consider both groups together.

Litter-size and total and average weight of litter include all pigs live and dead. The number of dead pigs was 7·4 per cent. of the total births.

If the quantity of food fed to brood sows were to affect the weight of their litters it might do so in either of two ways, namely, by altering the number of pigs (in which case the total weight would be affected), or by altering the individual weights of the pigs (in which case the average weight would be affected). Mere inspection of Figs. 2 and 3 suggests that if there is an effect at all, it is rather slight over the range of weights shown. Fig. 3 might be held to support the view that liberal feeding tends to increase the number of pigs born and therefore their total weight, in accordance with the results of Zeller, Johnson, and Craft [9], but with material no larger than that so far available in Edinburgh, it is quite possible that high fertility and considerable weight-increase merely happen to be associated. Fig. 4 illustrates the observed relation between fertility and increase in sow-weight.

Attention may be drawn to the large range of variation in average and total birth-weight. Figs. 2 and 3 show that sows putting on approximately the same weight often produce litters differing by as much as half a pound in average weight at birth, which is of the order of 20–25 per cent. Similarly, differences of the order of 30–35 per cent. of the average commonly occur in total weight of litter. Data appropriate to Figs. 2 and 3 are given in Table 2, which shows the amount by which the variance of total and average birth-weight would be reduced if the increase in sow-weight from mating to farrowing could be held constant. Prac-

tically no reduction would occur in respect of average birth-weight and only about 11 per cent. in respect of total weight.

A similar analysis has been made of the effect of the weight of the sow from the mating to farrowing on the three-week weight of the total litter. The weight-increase of the sows during the last month of pregnancy, their actual weight at farrowing, and the weight which they put on to themselves as distinct from their litters have been examined in relation to the total and average weight of the pigs at birth and their total weight at three weeks. The weight which the sows have been deemed to put on to themselves has been calculated by subtracting from the weight after farrowing the weight at mating (an adjustment for weight after farrowing having been made in a few cases). The results are summarized in Table 2.

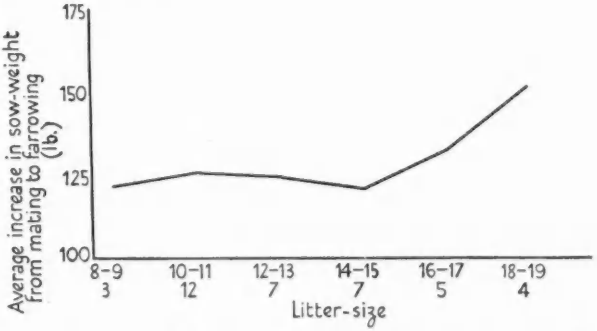


FIG. 4. Relation between litter-size and average increase in sow's own weight from mating until farrowing.

The conclusions indicated by the data in this table are that total birth-weight increased with increasing weight of the sow as measured both during the whole pregnancy and during the last month of it; and the total weight of the sow just before farrowing (including, therefore, the weight of the litter) had a similar relationship, but perhaps rather closer than that to be expected solely from the fact that her weight would obviously include the weight of the litter. As opposed to all this, the amount of weight which the sows themselves put on, that is the difference between their weights at mating and just after farrowing, failed to show any relation to the total weight of the litter. This suggests that the significant regression of total birth-weight on increase in sow-weight is due to the inclusion of the litter-weight itself in the latter. The principal conclusion so far, therefore, appears to be that there is at most only a slight connexion between total litter-weight and weight-increase of the sows. Different results would probably be found if the normal food requirements of sow and litter were not satisfied. Another clear fact is that the heaviest sows had the heaviest litters, but the importance of this statement is somewhat diminished by uncontrolled fertility differences and by the inclusion again of the weight of the litter itself.

That average birth-weight showed no relation to sow-weight or increase in weight also tends to discount the results in the previous paragraph. There is, indeed, a significantly smaller variance due to regression than that to be expected from chance alone, for which there

TABLE 2

Variance	*D.F.*	*Sum of squares*	*Mean square*	*Significance*	*Per cent. of total variance due to regression*
A. Total birth-weight					
Total	39	1796·40	46·06		
Due to regression on (1)	1	206·75	206·75	S	11·51
Remainder	38	1589·65	41·83		
Due to regression on (2)	1	185·43	185·43	S	10·32
Remainder	38	1610·97	42·39		
Due to regression on (3)	1	384·17	384·17	SS	21·39
Remainder	38	1412·23	37·16		
Due to regression on (4)	1	89·42	89·42	NS	4·98
Remainder	38	1706·98	44·92		
B. Average birth-weight					
Total	39	3·513	0·901		
Due to regression on (1)	1	0·044	0·044	NS	1·25
Remainder	38	3·469	0·091		
Due to regression on (2)	1	0·00035	0·00035	S*	0·01
Remainder	38	3·513	0·092		
Due to regression on (3)	1	0·026	0·026	NS	0·73
Remainder	38	3·487	0·092		
Due to regression on (4)	1	0·064	0·064	NS	1·82
Remainder	38	3·449	0·091		
C. Total weight at 3 weeks					
Total	35	33363·12	953·23		
Due to regression on (1)	1	765·34	765·34	NS	2·29
Remainder	34	32597·78	958·76		
Due to regression on (2)	1	20·45	20·45	NS	0·61
Remainder	34	33342·67	980·67		
Due to regression on (3)	1	1197·80	1197·80	NS	3·59
Remainder	34	32165·32	946·04		
Due to regression on (4)	1	919·46	919·46	NS	2·76
Remainder	34	32443·66	954·23		

* Significantly less than expected.
(1) Weight-increase of sows from mating to farrowing.
(2) Weight-increase of sows during last month of pregnancy.
(3) Total weight of sows at farrowing.
(4) Weight-increase of sows apart from litter from mating to farrowing.
S = significant over 5 per cent. point but below 1 per cent. point.
NS = non-significant. SS = significant over 1 per cent. point.

is probably no biological reason. Negative results were also obtained in relation to three-week weights, which have clearly been unconnected with the weight of the sow. In contrast to this result, Zeller, Johnson, and Craft [9] found at Beltsville that the heavier sows at farrowing weaned more and heavier pigs.

In the last column of Table 2 is shown the amount of the variance in total birth-weight, or average birth-weight, or three-week weight, which would be eliminated when sow-weight or weight-increase was held constant. The amount is negligible except for total birth-weight, but it would not be safe to conclude that as much as 10–20 per cent. of the variance would be lost with another group of sows in the same weight-range but with a different relation between weight and fertility.

Relation between Sow-weight or Increase in Weight and Variability in Birth-weights

It is conceivable that if competition among litter-mates *in utero* were responsible for their variability in weight at birth, the provision of sufficient nutriment for the needs of all would decrease that variability. A comparison has therefore been made of the variability within each litter (reckoned as the mean square deviation) with certain of the sow-weights used previously. The method of correlation has been employed for the purpose and the coefficients obtained are given in Table 3.

TABLE 3. *Correlation Coefficients*

Intra-litter variance and	*Sows* (30)	*Gilts* (10)	*Sows and gilts* (40)
weight of sow after farrowing	−0·074	+0·251	+0·070
weight-increase of sow from mating until just after farrowing	−0·368	−0·014	−0·267

5 per cent. levels of significance [10] for r are 0·349, 0·576, and 0·304 for n equal to 30, 10, and 40 respectively.

Of the coefficients given, only one seems unlikely to be due to a chance association. If it measures a real correlation, then in the sow group an increase in the body-weight put on by the sow during pregnancy has been associated with a decrease in the variance of the litter. Whilst confirmation of this conclusion is desirable, it may perhaps be used in considering the relation of sow and litter *in utero* until more extensive data are available. With this reservation it may be concluded that the actual weight of the dam has little or no influence on the variability of the litter, but that her weight-increase may have some. Little importance can be attached to the value of the coefficient for weight-increase and litter-variance for gilts, owing to the small numbers.

Discussion

The salient fact emerging from this experiment is that the attempt to increase the weight of pigs at birth by liberal feeding of their dams has failed. The numbers of pigs per litter may have been increased slightly, but not their average weight. During their pregnancies the sows put on a great deal of weight, so that the capacity of their digestive organs to absorb nutriment is not the limiting factor in foetal development. If the possibility that a qualitative deficiency in the diet existed is disregarded, the absence of any marked relation between the weight the sows put on themselves and the weight of their litters indicates that

either the foetal pigs are unable to utilize fully the available food supply, or they are limited in their growth by the mechanism for the nourishment of a litter *in utero*. The first alternative seems unlikely in view of the long time during which natural selection must have favoured those animals genetically best fitted for uterine growth, and of the occasional occurrence of whole litters of relatively large pigs. Lush, Hetzer, and Culbertson [11] attribute only 6 per cent. of the total variance in birth-weights of gilts' litters to heredity. The double-mating experiments of Carroll and Roberts [12], and of Shearer, Evvard, and Culbertson [13], also indicate that variation in birth-weights is but slightly affected by heredity.

The performances of gilts as compared with those of sows support the view that at the level of nutrition concerned there is no great difference in their relative abilities to nourish their young during pregnancy. It has been established by many investigators that the fertility of gilts is lower, and consequently the only difference between sows and gilts would appear to be in the numbers of eggs successfully implanted, and not in any immaturity of uterus.

The results obtained by Mohler [14] do not seem to be quite comparable with those now presented. He found that five small-type Poland-China sows averaged 4·2 pigs born, as compared with 6·7 pigs from eleven intermediate and large-type sows; sow-weight was associated with an effect on fertility, but the sows were, purposely, not homogeneous as were those used in our investigation; and thus genetic differences in either fertility or ability to nurture pigs *in utero* may be involved. If the latter alternative is correct, the Beltsville results may be regarded as evidence of the differences in uterine level of nutrition discussed above.

Summary

1. An attempt to increase the average weight of pigs at birth by liberal feeding of the dams during gestation failed. The amount of the variance in average weight per litter due to differences in (*a*) weight-increase from mating till just before farrowing, (*b*) weight-increase during the last month of pregnancy, (*c*) total weight of sow just before farrowing, and (*d*) weight-increase of sow herself from mating till just after farrowing, was negligible.

2. Total birth-weight was not affected by the weight-increase of the sow herself during pregnancy.

3. Three-week weight of whole litters was not affected by either (*a*), (*b*), (*c*), or (*d*) above.

4. No relation between intra-litter variance in birth-weight and weight of sow after farrowing was observed. Sows considered apart from gilts showed a negative correlation (just significant at the 5 per cent. point) of −0·37 between weight-increase of sows from mating till just after farrowing and litter-variance in birth-weight.

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EXPERIMENTS ON COMPOST-MAKING

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Pt. I. *The Nature of the Problem*

1. In considering methods of manufacturing compost, there is no need to go into the general question of the relative value of organic and inorganic manures. It may be assumed that in any sound system of agriculture, precautions must be taken to keep up the amount of humus in the soil. At the same time, since it is not possible to grow crops without straw, usually in greater quantity than is needed to feed the animals whose labours have produced those crops, the farmer has usually a quantity of waste organic material at his disposal to utilize for this purpose. The question then narrows itself down to the discovery and application of the best methods of converting this material into humus.

2. Such straw or similar organic matter must be considerably modified before it can be utilized by the plant. As this process proceeds by steps, it is important to decide how far it should proceed *before* the material is added to the soil. Obviously the cheapest way of dealing with straw is to plough it in immediately after the harvest of the heads, only removing what is actually required for the nutritional needs of the working animals, but there are considerable disadvantages in doing this, which so far have prevented its adoption to any great extent. The moisture in the soil at harvest-time is generally low and insufficient to promote decomposition, and that moisture may be rapidly lost by the openness of the soil brought about by turning under the straw. Toxic substances may be produced, whilst even in the most favourable circumstances the process of decomposition implies a locking up of a considerable proportion of the soil nitrogen, with a possible depressing effect on the succeeding crop. There is reason to hope that these difficulties can be partially, if not wholly, overcome, and the question is under investigation at Rothamsted [1].

3. A similar difficulty is experienced in the turning under of a green-manure crop, the growing of which is a common practice in the tropics, where conditions of warmth and moisture tend both to deplete the stores of humus in the soil, and to provide opportunities for growing green crops to replace them. The use of such crops may be most beneficial if the succeeding crop is planted at exactly the right time after ploughing in the green manure. If decomposition is unduly delayed, or the succeeding green crop is sown too soon, then the crop may suffer from immobilization of soil nitrogen. To wait too long for complete decomposition is to run the risk of soil nutrients being leached out of the soil by heavy rain.

4. Accordingly, the opinion that a certain amount of decomposition of raw organic material is desirable, before it is incorporated into the soil, is widely held. The temperate-climate farmer pins his faith to cattle, which he keeps and fattens equally for their sale as beef and for their services in

turning his straw into manure. The process is simple, and implies the minimum of handling, but necessitates a relatively large number of animals. The manure-making powers of the animals can be increased—but at an increase in cost—by adopting some modification of what is known as the Mauritian pen system [2].

5. In many parts of the tropics the keeping of animals is precluded by the presence of the tsetse fly, and the question of pre-decomposition in this case is of considerable importance, for any method of composting is bound to be expensive. Before discussing methods of composting, it is therefore important first to find out whether pre-decomposition in the tropics is generally necessary, and, if so, to what extent. The Chinese farmer, whose practices have claims to great consideration [3], is quite definite on the subject, and goes to considerable trouble to pre-decompose every scrap of the manure he uses. It was to throw some light on these points that the experiments described below were initiated.

Pt. II. *The Value of Pre-decomposition as shown by Field Experiments*

6. The first field-test of compost on the College Farm was made in 1934–5, when pen manure was compared with two kinds of compost, one made from maize-straw and the other from haulms of *Phaseolus mungo*. These three organic manures were applied at two rates, viz. 5 tons and 15 tons per acre, to a dry-weather crop of sorghum. Moisture proved to be the limiting factor, and no significant results were obtained, though there was no indication that the composts were inferior in any way to the pen manure. In the next year, a test was made to compare pen manure with chaffed-maize compost and with compost made from village rubbish [4]. These were applied in two quantities, 10 tons and 20 tons per acre, alone, or in combination with artificials, to a maize crop, with the results shown below. The compost in this case proved to be decidedly inferior to the pen manure used, but there was little difference between the latter and the village-refuse compost. Varying the rate of application did not produce any significant increase over the control.

Table 1. *Manurial Experiment with Maize*

Main plots:	*No artificials*	*Artificials*	*Totals*
No organic . .	100·0	99·8	100·0
Single organic .	99·2	109·1	104·2
Double organic .	105·9	101·2	103·6
Totals . . .	100·0	101·7	..

Weights of cobs as percentages of yields on control plots. Plots 1/24 acre. Six replications.

7. A further experiment was then arranged to test the value of the composting process by comparing finished compost with raw chaffed maize-straw, as a manure for maize. The compost was applied at the rate of about 10 tons to the acre, and the weight of straw was calculated

to apply the same quantity of dry matter. The crop was sown late, moisture was the limiting factor, and the yields obtained were small. In these conditions the compost proved decidedly superior to the maize-straw.

TABLE 2. *Manurial Experiment with Maize*

	No artificials		*Artificials*		
Sub-plots:	*Single*	*Double*	*Single*	*Double*	*Totals*
Pen manure	100	100	100	100	100·0
Compost from maize-straw . .	95	*87*	93	*86*	90·6
Compost from village waste . .	103	92	95	102	98·4

Weights of cobs as percentages of yields on pen-manure plots.
Plots 1/72 acre. Six replications. Figures in italics are significant at the 1 per cent. point.

TABLE 3. *Manurial Experiment with Maize*

Treatment	*No. of cobs*	*Wt. of cobs lb.*	*Wt. of straw lb.*	*Shelling, per cent.*
Compost .	551	208	*571*	68·9
Straw .	507	186	*460*	64·0

Plots 1/36 acre. Four replications. Figures in italics are significant at the 5 per cent. point.

On the plots receiving fresh straw there was a tremendous growth of volunteer maize, brought in by the manure, but careful thinning equalized the crop populations.

8. In the next year (1936–7) a more elaborate experiment compared the yields of maize manured with composts of three stages of decomposition with that manured with the raw material—chaffed maize-straw—from which they had been made. Half of each plot received a dressing of sulphate of ammonia. The results are given in Tables 4 and 5.

TABLE 4. *Comparison of Raw Maize-chaff with Compost of Varying Stages of Decomposition*

No.	*Treatment*	*Cob weight*	*Grain weight*	*Straw weight*
1	Control (no manure)	100	100	100
2	Raw chaffed maize	107	104	*114*
3	14-day old compost	104	105	*110*
4	32-day old compost	112	113	*119*
5	56-day old compost	107	109	*110*

Crop: Yellow dent maize; plots 1/30 acre.
Composts applied at 10 tons to the acre: chaffed maize at an equivalent weight of dry material.
Lay-out: Seven randomized blocks, each of five treatments.
Weights expressed as percentages of yields on control plots.
Figures in italics are significant at the 1 per cent. point.

Careful growth-studies were made, but failed to show any significance; nor was there any significance in the yields of cob or grain. The yields of straw from all the treated plots were significantly greater at the 1 per cent. point than that from the control. The higher yield of straw from the sub-plots receiving ammonium sulphate was also significant at the 1 per cent. point. No significant interactions between main and sub-treatments were observed.

TABLE 5. *Effect of Ammonium Sulphate*

No.	*Treatment*	*Cob weight, per cent.*	*Grain weight, per cent.*	*Straw weight, per cent.*
1	Plots receiving no ammonium sulphate	100	100	100
2	Plots receiving ammonium sulphate	106	105	115

Crop: Yellow dent maize; plots 1/60 acre. Ammonium sulphate applied at 3·9 cwt. to the acre.

Lay-out: Two sub-plots to each of the plots in Table 4. Yields expressed as percentages of yields on control plot.

The results may be ascribed to the high state of fertility existing in the field at the time, sufficient nitrogen being available for the decomposition of the raw straw and the younger composts. The crop was a remarkably good one, and yielded an average of nearly 4,000 lb. of cobs per acre.

9. A later experiment, in the same year, compared the relative field values of compost made from long (unchaffed) maize-straw with that made from short (chaffed) straw. Three treatments were arranged. In the first the compost was made entirely from long maize-straw, which had been in the pen, under the feet of the cattle, for six days. In the second this material was mixed, in equal proportions, with short fresh maize-straw cut into ½ in. lengths, whilst in the third only short chaffed straw was used. Four heaps of each type were built, and after the first turning, sunn hemp was sown on two heaps of each type as a sub-treatment. All were applied when four weeks old, at the rate of 6·7 tons to the acre.

The chemical analyses of the four composts are given in Table 6 and illustrate a difficulty in experiments of this kind. All the types were to be made from the straw of one crop of maize, but an unexpectedly low yield made this insufficient for the purpose, and the chaffed-maize heaps, on which sunn hemp was not sown, were made from straw from another field that proved to be of much poorer quality.

The main-treatment results (Table 7) showed the general superiority of the long straw and the mixed straw compost over that made from chaffed straw, but unfortunately the value of this finding is reduced by the inequality of the original materials noted above. The sub-treatments failed to give significant results.

PT. III. *Methods of Estimating the Extent of Decomposition*

10. The general conditions in which organic matter is broken down to humus are fairly well known, and are described by Hutchinson and Richards [5]. The process, known as composting, depends on various

fungi and bacteria, and for decomposition to proceed satisfactorily these organisms must be present and conditions must be suitable for their rapid and healthy growth. As these conditions are, in practice, largely under the control of the maker of the compost, it is important to know what they are.

TABLE 6. *Analyses of Composts used in the Field Experiment*

Type of compost	*Moisture*	*On dry weights*						*C/N ratio*	*Degree of humification*
		Organic matter	*Carbon*	*Ash*	*Total nitrogen*	P_2O_5	K_2O		
L H	78·9	74·8	41·0	25·2	1·82	1·11	3·89	22·5	49·1
L O	77·3	73·6	39·1	26·4	1·82	1·13	3·69	21·5	48·9
M H	73·9	65·8	34·2	34·2	2·09	1·41	4·31	16·4	54·5
M O	69·4	72·1	34·4	27·0	1·89	1·17	3·83	18·2	48·2
S H	83·6	76·4	40·0	23·6	1·97	1·32	5·09	20·3	56·1
S O	71·5	81·2	43·5	18·8	1·42	0·88	1·67	30·6	54·3

L: made from long straw. M: from mixed straw. S: from short straw. H: sunn hemp sown on heaps. O: control.

TABLE 7. *Comparison of Different Composts*

Treatment	*Weight of 100 seedlings*	*Cob weight*	*Straw weight*
L	115	115	109
M	118	114	112
S	100	100	100

Crop: Yellow dent maize. Plots 1/17 acre. Eight replications in randomized blocks. Weights as percentages of 'S' plots. All figures significant at the 1 per cent. point.

11. Firstly, there is the supply of air and moisture to the fermenting mass. The two conditions are to some extent complementary and may be discussed together: they are the most important. Secondly, there is the supply of the organisms necessary to carry out the process. Thirdly, the nature of the material, such as its chemical composition, its pH value, its carbon-nitrogen ratio, and its physical structure. Experiments dealing with these points are described below. Except where otherwise mentioned, the material used was dry maize-straw cut into 1-inch lengths.

12. The first point to settle in carrying out these trials was to decide what criterion to use for determining the extent to which decomposition had proceeded. The most obvious is the loss in the dry weight of the fermented material, but this presents some difficulty owing to the very variable amount of moisture contained in the heaps. Careful determinations were made in one experiment in 1935–6, when differing quantities of water were added to heaps made of old compost mixed with fresh maize-chaff, with the results shown in Table 8. The loss in weight is seen to be a strict measure of the amount of decomposition, and is corroborated by the percentage of ash. Both criteria show that the medium heap failed for some reason to decompose properly.

13. An easier method is to record the temperatures produced within the heap, though certain precautions are necessary in taking and interpreting these figures. At first, readings were taken by lowering thermometers down hollowed bamboos embedded in the heaps as they were made, but it was found that around these tubes aeration was rather higher than in the rest of the heap, and after trials with soil probe-thermometers (which mostly are graduated only to read up to 50° C.) the following method was found satisfactory. Holes were made at random in the heap by means of a crowbar, and into these holes a thermometer was inserted. All readings were made at a standard distance from the outside of the heap, for considerable differences were recorded between temperatures taken 10 in. from the outside and 22 in., amounting to as much as 4° C. Temperatures reach their highest point in about three

TABLE 8. *Loss of Weight in Compost Heaps*

Heap	*Wt. at beginning*		*Total dry weight*	*Total dry wt. after 1 month*	*Loss*	*Loss per cent.*	*Ash per cent.*
	Maize-chaff	*Old compost*					
1 (wet) . .	1,731	998	819	660	159	19	26·1
2 (medium) . .	1,369	1,029	719	673	46	7	19·3
3 (dry) . .	1,229	1,229	737	501	236	32	25·9

days from the building of the heap, and this lies generally between 55° C. and 60° C., the highest recorded being 70° C. Thereafter the temperature falls slowly, reading about 30° C. after six weeks and remaining constant at that level.

14. Another criterion is the degree of humification, and this was determined on samples taken from the heaps, by treatment with hydrogen peroxide, according to the method of Robinson and Jones [6]. This figure served as a useful comparison between adjacent heaps; its actual value was small.

15. Two other methods of recording the measure of decomposition were tried. The amount of carbon dioxide evolved is proportional to the activity of the process, and attempts were made to measure it from small samples taken from the heap. Owing to the great variation in the material the sampling error was very high, being about 200 per cent.

16. Another method was to make a count of the micro-organisms present. The method adopted was the plate-count method worked out by Waksman and Fred [7] for use on soil samples, with the modification that the sample of 10 grams of compost was left in the broth of dextrose and peptone for 24 hours before plating out, instead of being done at once. It was thought that the organisms would not be shaken off a material like compost as easily as from soil particles. Various dilutions were tried, and a number of replications, but in this case, too, the material was found to be too variable for any use to be made of the method.

Bacteria are usually found in greater numbers than fungi, but on the one occasion when a count was made early in the life of the heap, the fungi outnumbered the bacteria. Later the position was reversed. It is

probable that the fungi, which include a number of species of *Aspergillus*, *Penecillium*, *Fusarium*, *Mucor*, *Acremoniella*, and *Coprinus*, function at a high temperature and are responsible for the early stages of decomposition, the bacteria taking up the work later. The fructifications of *Coprinus* are commonly seen growing on the outside of the heaps.

TABLE 9. *Numbers of Micro-organisms present in Composts*

Treatment	*Colonies per gram after 3 days*		*Colonies per gram after 42 days*	
	Fungi	*Bacteria*	*Fungi*	*Bacteria*
Control heap . .	3,296,000	488,300	7,691,000	9,768,000
Dunged heap . .	122,100	30,500	5,006,000	13,680,000

17. An estimate of the proportion of ash is a useful comparative measure of the progress of decomposition, but, like the criteria mentioned above, it implies careful sampling.

18. There is finally the judgement of eye and hand in which the colour, the texture, and the breaking-strain of the straw are all noted. More and more reliance is being placed on this criterion, which has the advantage of simplicity and takes account of the whole of the heap.

19. A comparison of the results obtained by these different methods illustrates their general unreliability. Four heaps were placed as follows:

TABLE 10. *Comparison of Methods of Estimating Decomposition in Compost*

Method	*Order of placing*
Temperature determination	1 4 2 3
Appearance . . .	4 1 2 3
Evolution of CO_2 . .	4 3 1 2
Fungus numbers . .	2 4 3 1
Bacterial numbers . .	4 2 3 1

PT. IV. *Factors Affecting Decomposition in the Compost Heap*

20. (*a*) *Moisture and aeration.*—It is only in recent years that a general agreement as to the relative merits of aerobic and anaerobic conditions has been reached, in favour of the former. It is true that anaerobic fermentation is utilized in certain processes, such as the modification of the Boggiano-Pico process known as the Hyganic system [8], but even here it is followed and completed by an aerobic fermentation, and the latter is now generally recognized as the most suitable for the farmer. In 1932, in accordance with accepted practice, three open concrete pits were constructed on the College Farm for dealing with organic refuse, but were soon found to be much less effective than heaps. Trials made in 1932–3 showed that lack of aeration was the difficulty. This caused the production of a silage-like material with an unpleasant smell, which resisted further decomposition. The pits were discarded forthwith for compost-making, and have since only been used for the storage of finished material.

21. An early experiment (1932–3) compared the effect of varying the fineness of the material, and straw cut into lengths of ¾ in. and 1 in. were used, with varying amounts of added water. The short chaff was slower to decompose, and as its preparation cost about twice as much as that of long straw, the practice was abandoned. It was early found that the height to which the heaps were built is a matter of first importance: the higher the heap, the less ground occupied, and the shorter the lead for carting material; but a heap may easily be too high, especially in the wet weather, and the extra pressure in the lower layers tends to produce anaerobic conditions.

22. Such anaerobic conditions can be immediately remedied by turning the heap, and this practice is almost universal, even if only to incorporate the drier outer layers of the heap where decomposition is at a standstill. Turning a heap for the first time promotes decomposition and is followed by an immediate rise in temperature: the second turning produces a like effect but on a reduced scale. Excessive turning tends to dry out the heap, and this will be beneficial or otherwise, according to the season and the state of the compost.

TABLE 11. *Effect of Turning Compost Heaps*

	Weight of dry matter		*Loss per cent.*	*Moisture, per cent.*		*Degree humification, per cent.*	
Treatment	*Start (lb.)*	*Finish (lb.)*		*Start (lb.)*	*Finish (lb.)*	*Start*	*Finish*
Heaps unturned .	410	318	22	60·4	66·1	25	49
Heaps turned weekly . .	428	264	39	60·4	29·5	25	50

In an experiment carried out in 1935 (Table 11) there were three heaps in each treatment, made of maize-chaff. The experiment ran from January to April, and thus fell entirely in the dry season, and moisture was obviously the limiting factor. Humification was much the same in both heaps, but the turned heap was very much drier than the unturned one.

A similar experiment in the following year (1935–6) compared unturned heaps with heaps turned weekly and turned monthly. The heaps were started in November and were on the wet side throughout, and it was noted that in this case turning had promoted decay and produced more uniform heaps.

The rise in temperature that may be expected to follow turning is shown by the figures below, which were taken at two points in the same heap; they show also, by their gradual convergence, how turning promotes uniformity.

23. The addition of water has a twofold effect, for in very dry conditions it may supply the moisture needed by the organisms, but in excess it may bring about anaerobic conditions through softening the material and thus enabling it to be compressed or by filling in the interstices to the exclusion of air. Too much of it at any time will act as a

diluent and slow down fermentation. The results of using water are therefore likely to differ.

Three heaps were built in January, 1936, of similar material. The first was built dry and under cover, the second was lightly wetted by dipping alternate forkfuls in water as the heap was built, whilst the third was fully wetted. The dry heap was first off the mark, and rapidly reached

TABLE 12. *Temperatures Taken in a Heap after Turning*

Time of reading	*Point A* °C.	*Point B* °C.	*Mean* °C.
December 19, 2 p.m.	34·8	39·2	37·0
4 p.m.	35·9	39·9	37·9
7 p.m.	37·8	40·8	39·3
December 20, 11 a.m.	41·8	41·4	41·6

The heap was turned at 8 a.m. on December 19.

a temperature of 73° C.—the highest recorded in any experiment—and lost one-third of its weight in three weeks, but stopped earlier than the others. The medium-wet heap was very slow in starting, whilst the thoroughly-wetted one decomposed satisfactorily. These differences are shown by the figures quoted below, which were taken three weeks after making:

TABLE 13. *Effect of Varying Moisture in Compost Heaps*

	Loss of dry wt., per cent.	*Moisture in compost, per cent.*	*Nitrogen on*		*Humification, per cent.*	*Ash on dry wt.*
			dry wt.	*fresh wt.*		
Dry heap . .	32	71·5	1·67	0·48	48·2	25·9
Medium-wet heap	7	78·1	1·53	0·33	47·4	19·3
Wet heap . .	19	80·6	1·67	0·32	54·0	26·1

24. The use of short material has been mentioned above, and reference may now be made to the use of long material. The expense of chaffing maize-straw is a very considerable item in the cost of compost-making (see para. 45), and if this material can be used without chaffing, a considerable saving will be effected. A quantity of maize-straw was carted into the pen and allowed to lie under the oxen for seven days, when it was carted out to the yard and built into two large heaps 5 ft. high and the same thickness. Very careful temperature-readings were taken in these two heaps, which for a time were treated similarly.

Very high temperatures were reached, the maximum being obtained 3 days after the first turning, which was done 14 days after the heaps were made. After 25 days, one heap was watered every evening, with approximately 10 gallons of water, and this had the effect of reducing the temperature. Temperature-readings taken 43 days after the heaps were started showed consistently higher temperatures at 1 ft. from the surface than at 2 ft., the readings being 60·4° C. and 56·6° C. in the two heaps at 1 ft., and 57·0° C. and 54·8° C. at 2 ft. This would indicate that some factor, presumably lack of aeration, was hindering bacterial and fungal

activities, a state of things rather unexpected in the dry season and with long straw. The final product, after 83 days, was a really good, well-rotted compost, and equal in quality to any produced from chaffed straw, whilst the saving in expense was considerable.

25. It is not possible from these experiments to give any definite standards of moisture and aeration for correct composting, but they show clearly the effect of varying these factors, and thus point out to the operator how he can control the operation.

26. (*b*) *Nature of material.*—The rate of decomposition appears to be largely influenced by the proportion between the readily decomposable constituents, celluloses, and pentosans, and the less readily decomposed substances, such as lignin. An excess of the latter may interrupt decomposition almost entirely. Fortunately, most of the materials available to the agriculturist, like cereal straw and sugar-cane trash, are high in celluloses and decompose without trouble. No experiments have been conducted with cotton stalks or pigeon-pea (*Cajanus indicus*) stalks, though the latter, even when unmixed with other materials, have been found to produce a very good sample of compost.

27. It has already been shown how the physical nature of the material affects the aeration of the heap. Soft material like rice-straw, which here is rather sappy, may give trouble, especially in wet weather, and a comparison was made of different methods of dealing with this material. In 1936–7 three heaps were made, as follows: Heap 1 was made of fresh long rice-straw, well wetted with dilute urine. Heaps 2 and 3 were made of straw that had been in the pen, under the feet of the cattle, for four days; Heap 2 was used by itself, but some long maize-straw was incorporated in Heap 3, in order to promote aeration. Heap 2 was the most successful; ultimately it became dark in colour and practically structureless. Heap 1 was fair, but the structure of the flattened straws was still quite visible, whilst in Heap 3 the maize had scarcely decomposed at all. The following figures are interesting, as showing the extent to which decomposition had proceeded in 12 weeks:

TABLE 14. *Decomposition of Composted Heaps of Rice-straw*

	Dry matter			C/N ratio	*Degree of humification, per cent.*	*Temperatures* (°C.)			
	Organic matter	*Ash*	*Nitrogen*			*After 1 wk.*	*After 2 wks.*	*After 4 wks.*	*After 8 wks.*
Rice-straw fresh	82·8	17·2	0·63	..	..	..	..	..	..
Heap 1	46·0	54·0	1·55	14·5	80·0	32·2	38·3	39·4	42·2
Heap 2	46·6	53·4	1·67	12·6	73·2	58·1	38·0	35·2	38·4
Heap 3	40·7	59·3	1·55	12·9	77·5	44·2	40·3	36·6	41·2

The haulms of *Canavalia*, though probably better from the point of view of composition, being richer in nitrogen, were found to be too tough and woody for rapid decomposition and needed greater compression.

28. The chemical composition of the material has received more attention, as it is to some extent under the control of the experimenter, who endeavours to maintain the correct pH value, and the correct carbon-

nitrogen ratio. Acidity is always liable to occur, especially under anaerobic conditions, and produces what may be called a 'silage' complex, when further decomposition is checked. An experiment carried out in 1934–5 throws some light on this point as well as on the question of the addition of nitrogen. Four heaps were built, each of 5 cwt. of chaffed sorghum-straw mixed with 1 cwt. of old compost. To the first two 25 lb. ammonium sulphate were added, supplemented in the case of Heap 2 with 40 lb. of finely-ground limestone. To the third heap nothing was added. In the fourth heap 75 lb. of fish manure was used as the source of nitrogen. In Heaps 1 and 2 the nitrogen-content was reckoned to be about 1 per cent., in Heap 4 it was rather less. Regular pH determinations made in Heaps 1, 2, and 3 showed clearly that where sulphate of ammonia was added, acidity was gradually developed; the process is not very much checked by the addition of lime.

TABLE 15. *Development of Acidity caused by Addition of Ammonium Sulphate to Compost Heaps*

	Heap 3 control	*Heap 1 ammonium sulphate*	*Heap 2 ammonium sulphate, limestone*
At start	pH 6·8	pH 6·8	pH 6·8
After 10 days	6·8	6·8	6·8
„ 20 „	6·8	6·4	6·5
„ 30 „	6·7	6·3	6·3
„ 40 „	6·7	6·3	6·4
„ 60 „	6·6	6·2	6·2
„ 73 „	6·7	5·9	6·2

Temperature-differences were very slight, and at the end of the experiment, after 73 days, no difference between the heaps was visible, all being first-class compost. Analyses made at this stage gave the following results:

TABLE 16. *Analyses of Compost Heaps*

Treatment	*Moisture per cent.*	*Nitrogen, per cent.*	*Degree humification, per cent.*
Heap 1 control	54·1	0·89	43·8
„ 2 sulphate of ammonia	57·1	1·09	51·9
„ 3 S/A, and limestone	57·2	1·02	63·0
„ 4 fish manure	57·2	0·94	54·1

The lime appears to have facilitated humification, though it did not reduce the acidity of the compost. It may be concluded that the addition of lime is unnecessary except perhaps when ammonium sulphate is being used.

29. The addition of nitrogen to correct the carbon-nitrogen ratio of the material has been recommended by many writers, and has been investigated. An experiment in 1932–3 compared the addition of nitrogen added as ammonium sulphate in sufficient quantity to bring the percentage of nitrogen up to 1 per cent., with the addition of half that

quantity, and with a control receiving none. Observations made on these heaps showed that the addition of nitrogen accelerated the decomposition, the full-nitrogen heap decomposing rather more rapidly than the half-nitrogen; the no-nitrogen heap caught up later and was very nearly as well decomposed as the others, though it remained slightly lighter in colour.

30. In 1934–5 equivalent quantities of organic nitrogen, supplied as dung and urine, and as ammonium sulphate, were compared with a control which received no nitrogen. The temperature records showed that the 'artificials' reached the highest maximum (70° C.), the control heaps came next (68° C.), and the dunged heaps were third (57° C.), but in spite of this, the dunged heaps were (when the heaps were examined six weeks from the start) definitely the best in appearance. Analyses taken at this time gave the following figures:

TABLE 17. *Analyses of Compost Heaps Receiving Organic and Inorganic Nitrogen*

Treatment	*Nitrogen in dry matter, per cent.*	*Degree of humification, per cent.*
Dunged . . .	1·45	35·60
Artificial . . .	1·53	29·09
Control . . .	1·44	28·98

31. Another experiment carried out in 1934–5 compared the addition of 7·5 lb. of ammonium sulphate containing 1·5 lb. nitrogen, with 2 bucketfuls of urine and washings from the cattle byre, estimated to contain about the same amount, along with two controls. The two control heaps showed the highest temperatures, but all the heaps, at the end of three months, had the same appearance. From analyses made, it would appear that the urine treatment had been rather a failure.

TABLE 18. *Analyses of Heaps Receiving Organic and Inorganic Nitrogen*

Treatment	*Nitrogen in dry matter, per cent.*	*Degree of humification, per cent.*
Sulphate of ammonia .	2·06	51·88
Urine and washings .	1·89	44·72
Control . . .	2·06	52·43

32. In 1935–6 three heaps to which ammonium sulphate was added at the rate of 1 lb. S/A to 70 lb. dry material were compared with three heaps to which nothing was added. Little difference was noticed between the heaps at first, but subsequently decay became suspended in the ammonium-sulphate heaps and the temperature dropped to normal. The trouble was due to the excessive acidity developed, which was sufficient to stop all bacterial activity.

There has been a considerable loss of nitrogen from the heaps to

which ammonium sulphate was added. The equivalent of 0·3 per cent. of nitrogen was added, and yet the finished heaps contained only about 0·1 per cent. more than those which received no added nitrogen. In other words, over half the added nitrogen has been lost, since the final weight of manure is approximately equal to the initial weight of dry straw. Unless it can be shown that the addition of nitrogen is actually necessary to promote decomposition, it would be more economical to apply it directly to the land.

TABLE 19. *Acidity developed in Heaps to which Ammonium Sulphate has been added*

Treatment	pH	*Temperature at end of experiment*	*Nitrogen in compost, per cent.*
Heaps receiving nitrogen .	5·1	28·6	0·44
Heaps not receiving nitrogen	7·3	39·6	0·36

33. It has been suggested that where nitrogen is shown to be necessary, it could be cheaply obtained from the air through the medium of legumes. Fresh stalks of sunn hemp contain 0·93 per cent. nitrogen (3·64 per cent. on the dry matter), and by mixing such material with dry cereal-straw of about 0·75 per cent. nitrogen on dry matter, it should be possible to get a wide range for the C/N ratio. It has further been suggested that legumes could be actually grown on the compost heaps themselves, with which they could be incorporated at the time of turning. This has been tried with moderate success (paragraph 9). Such plants produce an extensive root-system, but frequently do not develop nodules.

34. It has been also suggested that the addition of an energy-rich compound, like molasses, to compost heaps, would promote decomposition, especially in the dry season, when the heaps tend to dry out. Two experiments to test this theory were made in 1937–8, but gave discordant results. In the first, 4 galls. of molasses, diluted to 10 galls., were added, during building, to a heap containing 72 cu. ft. and weighing about 1,260 lb.; to another similar heap 10 galls. of water only were added in the same conditions. At the second turning, in a month's time, a further 8 galls. of molasses were added to the 'molasses' heap. At the third turning this heap was seen to be superior, being dark in colour, moist, and with an excellent growth of fungi.

35. On repeating this experiment, the results were just the opposite. Two large heaps of 255 cu. ft. were built of chaffed maize-straw, in one of which 20 galls. of molasses were incorporated. From temperature-readings taken in the two heaps it was clear that the control heap was decomposing more rapidly. At four weeks both heaps were turned, and a second application of 10 galls. of molasses given to the 'molasses' heap. The experiment lasted eleven weeks, when it was found that the 'molasses' heap was cold, devoid of fungus, and practically unchanged. The cause of this arrest of decay was found to be the acidity developed in the 'molasses' heap.

It is not known whether acidity was developed to any extent in the

TABLE 20. *Effect of adding Molasses to Composting Maize-straw*

Treatment	*Age*	*Comparative density (approx.)*	*Moisture, per cent.*	pH	*Nitrogen, per cent. of dry weight*
Standard	After 4 weeks	183	80	7·8	..
Molasses		100	29	3·8	..
Standard	After 8 weeks	269	72	8·2	
Molasses		100	37	5·6	..
Standard	After 11 weeks	337	59	7·3	1·75
Molasses		100	36	2·5	1·05

'molasses' heap in the first experiment, but it may be presumed that it was not. A possible explanation of the discordant result obtained may be that, although a heavier dressing of molasses was used in the first experiment, it was applied one-third at the start and two-thirds at the later application: this was reversed in the second experiment, in which the heavier application was given first (Table 21).

TABLE 21. *Molasses used in two Compost Experiments*

		Proportions of molasses to maize-straw
First experiment	First application	1 gall. molasses to 18 cu. ft.
	Second ,,	1 ,, ,, 9 ,,
	Total ,,	1 ,, ,, 6 ,,
Second experiment	First application	1 ,, ,, 12·75 cu. ft.
	Second ,,	1 ,, ,, 25·5 ,,
	Total ,,	1 ,, ,, 8·5 ,,

A somewhat similar result was obtained by Tambe and Wad [9]: molasses used on fresh cane-trash failed to effect any appreciable fermentation, but with six-months-old heaps it was most successful.

36. (*c*) *Inoculation.*—Unless the organisms are present in large numbers, decomposition may be slow and irregular, so that thorough inoculation is frequently recommended; and, in dealing with village waste, it has been shown that new material ***must*** be mixed with at least its own bulk of actively fermenting material [4]. Several experiments have been conducted to estimate the necessity, in the conditions that obtain here, for any such step. After preliminary observations in 1932–3, an experiment was devised in 1934–5 to compare 'activated' compost (i.e. compost from a heap actively fermenting), with dung, as an inoculum. A rough determination of the bacteria contained in these substances showed that 22 lb. of dung was equivalent to 4 cwt. activated compost, and these quantities were incorporated in two heaps containing about 12 cwt. of *Canavalia*-haulm and 8 cwt. of maize-chaff, a mixture which was estimated to give a nitrogen-content for the whole heap of about 1 per cent. Unfortunately, the *Canavalia*-haulm, as mentioned above, is very open and fibrous, and the heaps tended to become too dry for correct decomposi-

tion. Analyses taken after three months showed little difference in the heaps. A further experiment was then tried to compare the addition of 22 lb. fresh dung, and 2 cwt. and 4 cwt. activated compost with a control to which no inoculating material was added. The differences between these treatments were slight, and are set out below:

TABLE 22. *Analyses of Heaps Inoculated in Different Ways*

Treatment	*Nitrogen in dry matter, per cent.*	*Degree of humification, per cent.*
Control—not inoculated	2·35	55·1
Inoculated with dung (22 lb.)	2·11	55·5
Inoculated with 2 cwt. activated compost	2·27	51·3
Inoculated with 4 cwt. activated compost	1·60	57·7

37. The next year this experiment was repeated (1935–6), using only 'activated' compost and incorporating different quantities with fresh maize-chaff. This experiment also was combined with the use of added nitrogen. Results here were more conclusive (Table 23), and after six weeks the heaps receiving the heavier inoculations were superior, both in appearance and in analysis.

TABLE 23. *Analyses of Heaps Composted with Varying Amounts of Inoculum*

Treatment	*Nitrogen in dry matter, per cent.*	*Degree of humification, per cent.*	*Ash per cent.*
No nitrogen			
Control	1·49	49·6	19·7
20% inoculum	1·50	52·0	37·1
50% ,,	1·50	55·0	40·8
Nitrogen added			
Control	2·15	41·4	21·2
20% inoculum	2·19	43·8	30·7
50% ,,	1·87	47·6	34·3

These differences became less pronounced later on, and at the end there was nothing to choose between the three inoculation treatments. In a further experiment, a comparison of compost and pen manure, alone or mixed, for the purpose of an inoculum, showed up the general superiority of the pen manure.

38. There appears to be no need here for a second inoculation, as suggested by Howard, on the ground that the heat developed at the start of decomposition may sterilize the heap.

39. The addition of small quantities of refractory material to larger quantities of actively decomposing material, rather on the lines of the activated-compost system of Fowler [10] may be mentioned here. A lorry load of grape-fruit skins from the Canning Factory was incorporated in a large heap of maize-chaff compost, and was very quickly decomposed. Once a good store of actively-rotting compost is available,

almost anything can be conveniently and inoffensively disposed of in this way and made to contribute to the manure supply.

Pt. V. *Practical Composting*

40. The results of the experiments described above are at first sight disappointing, for they give indefinite and at times conflicting results. This indicates one of the chief difficulties of giving instructions for making compost, and that is the impossibility of standardizing any process, in the widely varying conditions that are found. Most of the above experiments were conducted with a fairly uniform material—chaffed maize-straw—but even with the material standardized, variations in humidity and in inoculation upset calculations. It was found, for instance, that in a row of compost heaps, uniform in composition and size, the heap at one end—nearest to a low party wall—was always warmer than the others, because it was protected from the prevailing drying breeze. This was verified by taking readings from opposite sides of the heaps in the molasses experiment (para. 35). The east side, exposed to the prevailing wind, was in each heap consistently lower than the west or sheltered side, the difference being from 5° C. to 10° C.

41. In such circumstances it is possible to give only very general instructions; and firstly the need or otherwise for speed in decomposition must be settled. In growing vegetable crops in rapid succession, under irrigation, the material is probably wanted as soon as possible, and it is economic to use methods the expense of which would not be justified in a system of single-crop farming, where the straw from a five-month crop is not wanted as manure for seven months, when the next cropping-season comes round. Almost anything will decompose in time, but under control this period can, to a great extent, be standardized and farm work regularized. Thus, it has not been found necessary here to add any extraneous nitrogen to maize-chaff, except that conveyed in the small amount of excreta which is added for inoculation purposes, and for this dung is superior to urine. Nor is the use of lime found necessary or even desirable.

42. Far more attention must be paid to the aeration of the heap; this offers no difficulty when using stiff material like chaffed maize, but soft material, like rice-straw or fallen leaves, tends to felt together when wet, and the consequent exclusion of air stops or slows down decomposition. On the other hand, open or springy or ligneous material like cotton-stalks or *Canavalia*-haulms or old Para grass (*Panicum purpurascens*) may take a long time before they soften enough to become amenable to treatment. The size of the heaps in such cases becomes of the first importance, and much can be done by putting the more refractory material at the bottom of large heaps, where it will be compressed and moistened by the mass above. Turning is most efficacious in stimulating aeration, but turning, of course, implies expense.

43. The man who has live stock is at a great advantage in the preparation of compost, for the best treatment of any material before it goes into a compost heap is a period under the feet of stock, where it gets trodden and bruised and at the same time receives the necessary inocula-

tion. This period need not be as long as is sometimes thought, and the process now adopted on the College farm is to clear the pen out regularly once a week, and build the material into heaps outside. There is indeed nothing new under the sun, for this is in effect the Mauritian system [2]. The subsequent treatment of these heaps depends on the time available for decomposition before they are wanted.

44. This system has the further benefit of reducing the fly population considerably, for no larvae can hatch out in the pen, and flies are apparently not attracted to the heaps. In 1934–5 the experiment was tried [8] of netting heaps of village refuse that were being composted, and it was shown that although the material was heavily infected when it arrived at the depot, it did not seem to form an attractive nidus when made up into compost heaps. Further experiments have been done along these lines in 1937–8, the material in this case being maize-chaff, and therefore probably less infected at the start. Very few house-flies have been found to breed from any of the heaps, at whatever age, after making up, they were netted. Other species, *Tipulidae*, *Syrphidae*, and one *Stomoxys* were found. It is not claimed that the system is absolutely fly-free, but it is incomparably better in this respect than the ordinary 'pen' or cattle byre.

45. Finally, a word as to the cost, which depends on the cost of material, the cost of the equipment, and the cost of labour employed in manipulation. The material is, in Trinidad, and in general, refuse matter, and its cost is merely that of its collection and transport. The cost of maize-straw may be put even below this, for the crop cannot be grown without producing straw; the straw is of no value for stock; and it must be removed before a succeeding crop can be taken, so that its removal may fairly be charged to the crop. If the system suggested in para. 43 above is to be carried out, some constructional work will be necessary. It is suggested that a concrete floor is desirable for the heaps, for without some such arrangement the constant carting from the pen will soon reduce the area to a sea of mud. This floor should drain back into the pen, so that any liquid expressed from the heaps would not be wasted; but arrangements should be made so that storm-water will be by-passed. The labour required for handling and turning has been carefully recorded, and for a ton of material composted, which may be taken generally as equivalent in weight to a ton of completed compost, the following data have been obtained:

	Man hours
Loading and carting	3·0
Chaffing (labour only)	3·0
Building heaps	6·0
Collecting dung and urine	0·5
Turning once	1·0
	13·5 at 6 cents an hour = 81 cents[1]

To this must be added the cost of animal traction for carting material, and the cost of running the chaff-cutter, which is here calculated at 54 cents a ton. The total cost of manufacture may therefore be taken in

[1] Two cents = 1*d*.

Trinidad at $1·35 a ton. Of this, the cost of chaffing is a considerable item, amounting to over a half, and it is obvious that the process by which most of the farm residues are now treated, described in para. 43, is most economical, for the finished compost should not cost more than 65 cents a ton, a most reasonable figure. If the compost contains a large proportion of moisture, this figure may be considerably reduced.

Pt. VI. *Summary and Conclusions*

46. The results of a number of experiments conducted by students of the Imperial College of Tropical Agriculture on compost-making are summarized. A note is added on the practical results of these experiments.

The conclusions reached are as follows:

(1) It is not possible, even with standard material, to lay down a definite programme for composting.

(2) The time available for decomposition affects the methods adopted, as the more rapidly decomposition is wanted to occur, the more expensive will the process become.

(3) Of the factors controlling decomposition, aeration and moisture are the most important.

(4) Correction for acidity has not been found necessary in the conditions obtaining.

(5) The use of inoculating material has not been found necessary unless very rapid decomposition is desired.

(6) By adopting a system similar to that described in para. 43, known as the Mauritian system, farm stock is most economically utilized for the decomposition of farm waste.

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WINTER KEEP ON TEMPORARY LEYS

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THE lack of uniformity in the seasonal production of pastures presents a number of practical problems. Thus at flush periods growth may be greatly in excess of current consumption, whilst during winter and early spring the shortage of green grass is often very acute. Both of these conditions are bad for grassland, for the overgrown condition of most pastures in summer promotes cumulative deterioration by favouring coarse herbage of low palatability, whereas the severity of spring grazing, as met with on sheep farms in particular, adversely affects the sward as a whole, and especially those grasses which have the longest growing-season. Any change, therefore, in the technique of pasture management which helps to level seasonal production must tend automatically towards the maintenance of better pastures and to increased efficiency in grassland farming.

The investigation described below was designed to find what winter and spring grazing could be made available on temporary leys subjected to different schemes of manuring and management, and the effect on the chemical composition of the herbage of these diverse methods of treatment.

Material and Methods.—The plots were laid out on Gorse Field, at the Welsh Plant Breeding Station Farm, on April 4, 1933 (Fig. 1). Two seeds-mixtures were sown on two contiguous half-acre blocks, as hereunder:

Rate of Seeding to nearest lb. per acre of Laboratory Viable Seed

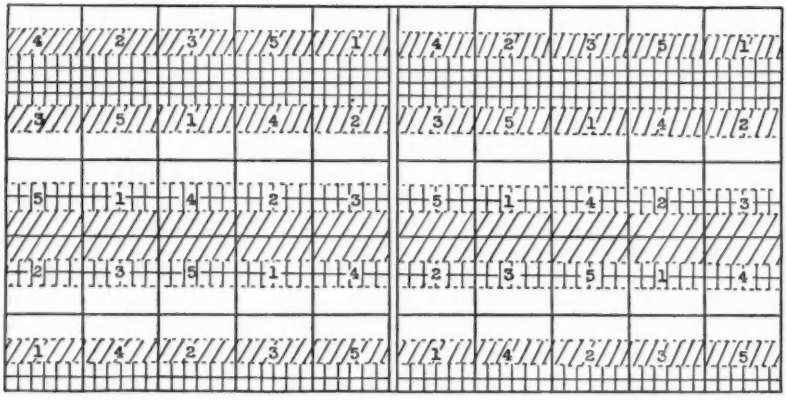
	Mixture A (pedigree)	*Mixture B (commercial)*
	lb.	lb.
Perennial rye-grass	8	9
Italian rye-grass	5	6
Cocksfoot	9	9
Timothy	7	7
Meadow foxtail	3	8
Dogstail	2	2
Rough-stalked meadow-grass	2	2
White clover	3	3
Red clover	3	3
Burnet (Poterium)	4	4

The divergence in seed-rates in Mixtures A and B is due to adjustment to real value on basis of laboratory germination (see *Welsh J. Agric.*, 1934, **10**, 144).

Each of the two half-acre blocks was then subdivided and fenced off into 1/50-acre folds, which were subjected to differential management. One-third of each fold was dressed with phosphate and nitrogen, one-

third received phosphate only, and the remaining one-third acted as control. Five cwt. basic slag (15·75 per cent. P_2O_5) per acre was applied in spring 1933, and a similar dressing in spring 1934, whilst 2 cwt. per acre of nitro-chalk was given in spring 1933, and again in autumn 1934.

Grazing throughout was by sheep, folded on the plots at concentrations of approximately 600 sheep per acre during each grazing-period, the sheep being moved from plot to plot as the food was consumed.



Management (for winter keep)

1. Rested November–February
2. Rested October–February
3. Rested September–February
4. Rested August–February
5. Rested July–February

Manuring

No manure

Basic slag

Basic slag plus nitro-chalk

FIG. 1. Plan of winter-keep trial. Gorse Field, E. 155.

The methods of management and manuring involved the following contrasts:

1. Day grazing versus night grazing in 1934.
2. No artificials compared with slag alone and with slag plus nitro-chalk.
3. Putting up for winter grass as from July, August, September, October, and November, respectively.

It is with the last-named aspect that the present paper deals in the main, although reference is also made to the other sections of the investigation, which include a comparison of the pedigree and commercial seeds.

'Putting up' for Winter Grass

Method of sampling.—Every plot was sampled before the sheep were put in to graze, 3 × 1 square-yard quadrats being cut from each 1/150-acre sub-plot. These samples were used for determination of air-dry weight as well as for botanical and chemical analyses. For the botanical work the percentage productivitiy method was used.

TABLE 1. *Average yield in lb. per acre and percentage Chemical Composition of Air-dried Grass from plots rested at five dates in the Autumn of 1934, and sampled on Feb. 26, 1935. (Series J to Y inclusive)*

Date 'put up' for winter grass	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
Yield of air-dried grass lb. per acre	742	620	487	398	320
Yield relative to 'put up' at 100	100	84	65	54	43
Chemical Composition					
Moisture	8·15	9·13	9·03	9·31	8·90
Ether-extract	3·38	3·80	4·10	4·30	4·41
Crude protein	14·83	16·51	18·23	20·24	22·10
True protein	12·41	13·00	14·10	15·15	16·10
Fibre	24·63	22·92	20·67	20·01	19·07
Ash	12·29	12·16	11·42	10·62	9·84
Nitrogen-free extractives	36·72	35·48	36·55	35·52	35·68
Phosphoric acid (P_2O_5)	0·59	0·65	0·73	0·76	0·78
Lime (CaO)	0·58	0·54	0·60	0·65	0·67

The above results refer in each case to the average yield of 30 sub-plots (each 1/150 acre) under different systems of manuring and management, all 'put up' at the date indicated, and sampled on Feb. 26, 1935, in their second harvest year. They include both the pedigree (station-bred) and ordinary commercial mixtures.

The heaviest yield, as the Table shows, is given by the plots rested from July, and the lowest by those 'put up' in November. The yield of the remaining plots is intermediate and dependent upon the date when enclosed. The chemical composition of the produce has also all the characteristic differences associated with old and young growth; this is particularly seen on comparing the protein- and fibre-contents of the produce of the plots 'put up' in July and November.

Careful notes taken on the plots showed that a considerable part of the herbage on these plots rested earlier than September was winter 'burned', and proved to be much less palatable than the herbage of those rested later than September. This was observed to be more pronounced on the commercial mixture where the Danish cocksfoot had become almost wholly 'burned', though the pedigree (station-bred) cocksfoot showed a considerable amount of leaf-burn on plots rested from July.

The general palatability of the herbage was markedly lowered when rested earlier than September, whereas the herbage on all plots rested from September onwards retained a high degree of palatability, and was completely and closely grazed by the sheep. On the plots rested earlier, there remained a quantity of unpalatable roughage which the sheep

refused to eat, though all the leafy material that remained green was readily consumed; indeed, it may be said that the palatability of the herbage was in approximately inverse ratio to the amount of winter 'burn' on the plots.

This roughage was mown with a scythe, removed from the plots, dried, and weighed. In extreme cases, such as some of the plots 'put up' in July, the roughage amounted to almost one-quarter of the total herbage.

The following statement gives the percentage by weight of 'burn' in the samples analysed in the laboratory, as well as the percentage of silica in the air-dried produce of the plots 'put up' at different times:

Date when 'put up'	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
'Burn' in produce, per cent. .	36·3	27·2	15·5	6·9	4·4
Silica (SiO_2) in produce, per cent. .	3·62	2·85	1·88	0·74	0·65

That a high proportion of 'burn' in the herbage has a considerable influence on its palatability and nutritive value will be readily appreciated from the following results obtained in a comparison of the chemical composition of the stem, leaf, and 'burn' of cocksfoot, cut on March 26, 1933.

	Stem	*Leaf*	*'Burn'*
Crude protein . .	18·00	25·00	11·94
Fibre	26·50	23·75	28·57
Ash	14·52	10·52	24·66
Silica (SiO_2) . .	3·31	3·87	17·45

It is seen from the above that the 'burn', compared with the stem and green portions of the leaf, is low in protein and high in fibre, and further that its percentage of ash and silica is particularly high: all of which have an adverse effect on the palatability of the herbage.

The botanical analysis of winter grass shows that well-marked changes take place in the herbage when the plots are given increasingly long periods of rest during the autumn. This is illustrated by the data given in Table 2.

TABLE 2. *Influence of date of 'putting up' on the percentage contribution of Rye-grass, Cocksfoot, and other species in the Herbage of Winter Grass sampled on Feb. 26, 1935. (Second harvest year)*

Month from which rested, 1934	*Percentage*				
	July	*Aug.*	*Sept.*	*Oct.*	*Nov.*
Rye-grass	34	41	51	59	64
Cocksfoot	41	44	32	28	21
Other species	25	15	17	13	15

Rye-grass in competition with cocksfoot is seen to be depressed in plots 'put up' as early as July, and its contribution to increase progressively in each of the succeeding months. Cocksfoot, on the other hand, gives

its highest relative contribution after a long autumn rest, and it is noteworthy that these changes occurred after only one season of differential treatment. This change in botanical composition has now become still more marked. Thus in July 1937 botanical analysis showed that on the pedigree plots 'put up' in July of each year the herbage consisted of only 12 per cent. rye-grass with 53 per cent. of cocksfoot, and there was more rye-grass and less cocksfoot proportionally on plots 'put up' at consecutively later dates. At the same time on plots 'put up' in November the contribution of rye-grass to the herbage was 38 per cent. and that of cocksfoot 15 per cent. This change in botanical composition has, therefore, been progressive from year to year.

A comparison of the yield and chemical composition of the winter grass produced by the pedigree (station-bred) mixture and the ordinary commercial seeds is shown in Table 3.

TABLE 3. *Yield of Air-dried Winter Grass in lb. per acre and average percentage Chemical Composition of the Herbage from Pedigree and Commercial Mixtures, rested at five dates in 1934 and sampled on Feb. 26, 1935. (Second harvest year)*

						Average	
Month when 'put up'	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Actual*	*Relative to pedigree = 100*
	lb.	lb.	lb.	lb.	lb.	lb.	
Pedigree mixture .	1,017	863	690	573	428	694	100
Commercial mixture	467	377	283	222	211	312	45

Chemical Composition

	July and Aug.		*Sept.*		*Oct. and Nov.*	
Date when 'put up'	*Pedigree*	*Commercial*	*Pedigree*	*Commercial*	*Pedigree*	*Commercial*
Moisture . .	8·77	9·08	8·20	9·72	9·01	8·99
Ether-extract . .	3·60	3·24	4·11	3·58	4·28	4·20
Crude protein . .	16·65	15·02	18·65	17·82	20·26	20·02
True protein . .	12·82	12·15	14·20	13·93	15·80	15·20
Fibre . . .	24·60	24·86	21·23	20·16	20·68	19·70
Ash . . .	11·90	12·75	10·27	10·12	9·00	8·04
N-free extractives .	34·48	35·05	37·54	36·60	36·77	39·05
Phosphoric acid (P_2O_5)	0·70	0·81	0·69	0·76	0·70	0·81
Lime (CaO) . .	0·64	0·76	0·59	0·61	0·60	0·71

It is seen that both pedigree and commercial mixtures have given their greatest gross yields when 'put up' in July. The yield of winter grass given by the pedigree mixture, however, is more than double that from the commercial in each instance, and when the average of all plots is taken, the commercial mixture is seen to have yielded only 45 per cent. of that provided by the pedigree mixture. These data provide striking evidence of the value of pedigree strains for winter keep on pastures. Not only have the pedigree plots given much higher yields than the commercial, but they have remained greener and consequently more palatable. It is important to note, however, that neither red nor white

clover has made any considerable contribution to the winter keep under these conditions: a fact that emphasizes the importance and value of the highly productive winter-green strains of grasses for this purpose.

The chemical composition of the pedigree and commercial mixtures given in Table 3 for July and August, October and November, represents that of composite samples from the produce of plots enclosed in these months. Comparison shows the difference between them to be more pronounced in the earlier than in the later enclosed plots. Thus, in the produce of those 'put up' in October and November it is negligible, whereas in those enclosed in July and August, although still small, it is certainly in favour of the pedigree mixture. This is in keeping with what has already been quoted from notes recorded at different periods concerning the appearance of the plots with regard to their winter greenness and amount of 'burn'. Small as the difference in chemical composition is between the produce of the two series of plots, it becomes of considerable significance when taken in conjunction with the large difference in yield of produce of the two series.

Day Grazing v. *Night Grazing*

Sheep grazing upon temporary leys tend to eat actively during the day, and to spend a high proportion of the night at rest. It is also well known that animals excrete more at night—including dusk and dawn—and this is one of the main reasons for the wide adoption of the night system of paddocking in New Zealand as a means of pasture improvement.

A somewhat similar custom prevails on many farms in Wales; in some cases this is for convenience, in others owing to poor fencing. Thus milking cows grazing a distant field during the day are at night frequently turned into another field adjoining the homestead for convenience of milking in the morning. Again, sheep grazing clover are at night removed to another field with the object of protecting the clover from trampling and fouling. Those who follow either or both these customs are well aware of the improvement brought about in those fields where the stock are enclosed at night, but whether the majority appreciate that the improvement is mainly attained at the expense of the fields grazed during the day is questionable. Where the custom is to change or rotate the fields that are night paddocked the benefit would then be more general.

To determine the effect of this practice on the yield and chemical composition of the produce, one series of plots was grazed during the day only, and a comparable series was always grazed over night. In Table 4 the average yield of dried grass in lb. per acre and the chemical composition of the produce of all the 'night' and 'day' plots is shown.

The average yield of 645 lb. per acre of air-dried grass on all the 'night' plots and of 386 lb. per acre on the 'day' plots gives a ratio of 100 : 60 for the two series, a ratio that is remarkably wide in view of the fact that the paddock system was only in operation during the 1934 season. The trial, however, is still in progress and the difference between the two sets of plots in subsequent years has become more pronounced in favour of the 'night' plots.

Reference has already been made to the influence that date of enclosing

the plots has on the botanical composition of the herbage; this is very strikingly seen on the night-grazed plots, where the rye-grass has been almost entirely suppressed on the plots 'put up' in July, whereas cocksfoot has been likewise suppressed where the grazing has gone on until November in each year. On the latter plots perennial rye-grass and white clover have become completely dominant.

TABLE 4. *Effects of 'Night' and 'Day' Grazing on the Yield and Composition of Pasture Herbage*

Plots	*'Night'*	*'Day'*
Average yield of dried grass on all plots, lb. per acre	645	386
Chemical Composition		
Moisture	9·09	8·81
Ether-extract	3·77	3·26
Crude protein	18·54	16·07
True protein	14·22	12·82
Fibre	21·56	21·23
Ash	8·91	7·09
N-free extractives	38·13	43·54
Phosphoric acid (P_2O_5)	0·92	0·71
Lime (CaO)	0·68	0·53

In considering the yield and chemical composition of the produce of the two series of plots, it should be pointed out that at the completion of each grazing-period any solid droppings left on the 'day' plots were collected and spread on the comparable 'night' plots.

As already mentioned, the yield of produce from the 'night' plots is so much in excess of the 'day' plots that it tends to mask any other difference. However, a comparison of the chemical composition of the produce of the two series of plots shows that of the 'night' plots to be richer in protein and mineral matter, and when this is taken in conjunction with yield, the superiority of the 'night' plots is very obvious.

Effects of Basic Slag and Nitro-chalk

To determine the effect of artificial manures on the yield and composition of the autumn and winter growth of grass, each plot was subdivided into three sub-plots. One-third acted as control, one-third received basic slag, and the remaining third received in addition to the slag a dressing of nitro-chalk (see pp. 369, 370).

The differences in yield became less in each successive year, so that at the end of 1937 they had practically disappeared. This equalization in yield in so short a time was doubtless partly due to the three sub-plots having been grazed as one unit, which would tend to bring the three to the same state of fertility.

Comparison of the chemical composition of the herbage of the three sub-plots shows appreciable differences in the contents of protein, mineral matter, and fibre of the manured as compared with the unmanured herbage. Thus the application of slag increases both the protein

and mineral matter, whilst the fibre-content is decreased, and when nitro-chalk in addition to slag is applied, these differences are still more marked.

TABLE 5. *Average yield of Air-dried Grass in lb. per acre of all three sub-plots and the Chemical Composition of the Produce*

	Control	*Phosphates*	*Phosphates + Nitro-chalk*
Yield of air-dried grass, lb. per acre	402	501	638
Chemical Composition			
Moisture	9·08	9·08	8·51
Ether-extract	3·74	3·85	3·92
Crude protein	16·23	17·92	18·66
True protein	13·30	14·81	15·23
Fibre	21·89	21·54	20·22
Ash	7·45	8·07	9·22
N-free extractives	41·61	39·54	39·47
Phosphoric acid (P_2O_5)	0·62	0·71	0·68
Lime (CaO)	0·56	0·67	0·74

Summary and Conclusions

1. The paper relates to the yields (including botanical and chemical composition) of winter grass from a temporary ley in the spring of the second harvest-year. Different systems of management and manuring are compared on both pedigree and ordinary commercial seeds-mixtures.

2. The pedigree mixture yielded more than twice as much winter grass, and was of higher nutritive value than the commercial mixture.

3. Cocksfoot was favoured by a long autumn rest, whilst rye-grass was favoured by a shorter autumn rest, when these two grasses were in competition with one another.

4. Night grazing, when compared with day grazing, markedly increased the yield of grass. The night-grazed plots produced grass richer in protein, phosphoric acid, and lime.

5. Both basic slag and nitro-chalk increased total yield, and also tended to increase the nutritive value of the herbage.

6. Plots rested from July showed a high proportion of winter 'burn', and in comparison with the other plots the herbage was less palatable.

7. Young temporary leys may be rested from early September in order to provide February-April grazing without much loss in nutritive value. Such leys rested completely earlier than September provide excellent late autumn keep, but where the crop is too heavy the herbage deteriorates in both palatability and nutritive value if left until spring.

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PARASITIC DISEASES OF FARM ANIMALS[1]

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THE close association between parasitic diseases and animal nutrition will be more easily understood if we carry ourselves back in imagination to the beginnings of man's interference with the balance of nature. Let us admit at the outset that throughout the stretches of evolutionary time everything ran *comparatively* smoothly until man made his appearance, and that the advent of his intelligence was of the nature of a calamity to all other zoological species.

We may suppose that early man was in some respects a gentleman, in that he spent his days in hunting and his nights in feasting. No doubt he sometimes returned from his hunting expeditions with young animals for his children to play with, and later, recognizing the possibilities of providing through this means for his own comfort and security, he contrived to encourage the breeding of certain useful animals in captivity and so set himself the task of protecting his tame animals from other beasts and providing for their food requirements. Through some such process as this primitive man came to exchange what must have been a very dashing if uncertain sportman's life for the humdrum cares of the husbandman.

If we would lay the blame for the present prevalence of parasitic disease upon any particular individual it must be upon that early genius who was the first to think of husbanding the patches of grazing near his own home, fencing them round to keep his domesticated animals from wandering, and reserving the choice grass for them alone. That man may be regarded as the first agricultural sinner, who deranged the natural order of things in the Garden of Eden, where the grazing animals had hitherto lived in peaceful equilibrium with their parasites.

One might describe the change by saying that the primordial state was one of harmonious community of happy worms in happy sheep, but since man's interference upset the balance one only too frequently sees a threatened annihilation of both. A satisfactory readjustment bringing the level of parasitic infestation within the tolerance of the host still awaits discovery.

It is generally admitted among graziers that the diseases caused by parasitic worms are the most economically important of all with which they have to contend. Most of us have been brought up to think that parasites are nasty creatures and that their only product is disease, so that it may come as a surprise to many to know that the very parasites which may give rise to so much trouble by excessive multiplication are normal inhabitants of healthy animals, guests of their alimentary tract. Disease is as harmful to the parasites as it is to their hosts, since it may

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lead to the death of the whole community. Parasitic disease is, therefore, to be regarded as a flaw in the environment and a departure from the primitive conditions to which the parasites had adapted themselves, rather than to a predaceous attack by small creatures upon a larger one.

So long as the number of worms in an animal remains reasonably and 'naturally' small, the balance of the ecological unit is maintained and a harmonious relationship continues, but disease follows where the numbers of the parasite community become excessively great. The increase of parasites, as we shall see, is essentially linked with progress in the improvement of pastures, worm diseases are man-made, and the artificial readjustment of the balance between the grazing animal and its parasites looms very large in the practical problems of animal production.

This readjustment will come only through a detailed knowledge of the reactions of the parasites both during their free life in the pastures and during their parasitic life in the grazing animal.

Mechanism of the development of parasitic disease among grazing animals.—The outline of the life-history of the parasites is comparatively straightforward. The adult female worms, situated in the lumen of the intestine, lay eggs which pass out of the grazing animal and on to the pastures; in the course of about twenty-four hours these hatch and give rise to minute larvae which, during the course of a week, cast their skin twice, and reach the infective stage at which they are ready to proceed with parasitic life as soon as they happen to be picked up by a suitable grazing animal.

For the proper understanding of the development of worm diseases there are three important points which require special consideration. The first of these is *the inability of parasitic worms to multiply in the body of the animal in which they are living*. This constitutes an important peculiarity in the propagation of worm diseases, distinguishing them from the kind of disease caused by bacterial or protozoan parasites, which are capable of multiplication within the body of the animal in which they are living. Where parasites can multiply in this way there is some reason for supposing that the initial infection is a most important step in the disease-producing process. If, however, every individual parasite requires to be picked up from outside, as is the case with parasitic worms, the relative importance of the initial introduction of infection appears to be very little indeed, and is of no practical consequence at all where, as with the parasites under discussion, all communities of animals, both healthy as well as diseased, are invariably infected. In such an instance as this it must be concluded that the *environment* of the grazing animal, which so largely governs the increase of the parasites, is of paramount importance.

The second important point to consider is *the remarkable egg-producing powers of the worms*. The egg production of some parasitic worms is numbered in tens of thousands daily per individual female, and although most of the worms with which we are concerned probably produce less, the daily output of eggs by infected grazing animals is very great indeed: a healthy sheep carrying an infection of trichostrongyles may pass some 200,000 to 400,000 eggs daily, and a diseased sheep between 9,000,000 and

30,000,000; a healthy horse carrying only a light infestation of strongyloid worms passes 1,000,000 to 2,000,000 eggs daily, and a diseased horse over 50,000,000. There is thus seen to be ample opportunity for the transmission of large numbers of worms under crowded grazing conditions, and this enormous output of eggs, which earlier in evolutionary time was developed to ensure the continuity of the species, is quite unsuited to present agricultural conditions.

The third important point to consider is *the longevity of the infective larvae of the worms in the herbage*. In the infective stage the larvae are ensheathed in a second outer skin, the result of incomplete moulting, and in consequence are endowed with great powers of resistance against cold, dryness, or other adverse forces acting upon them. They are also able to survive for an inconveniently long time in the herbage; patience may be said to be one of their vices, for some of them can wait twelve months, or even two years in exceptional cases, for a passing host.

Evil effects of overcrowding.—In view of the enormous output of eggs, even by healthy animals, and the longevity of the larvae on the pasture, it is clear that under agricultural grazing conditions there is liable to be a more or less rapid accumulation of infective material during the whole of the time that a pasture is occupied by grazing animals; and the evil effects of overcrowding may now be more fully appreciated. It is obvious that the more animals that are put on to a field the more eggs will be disseminated, and the more infective larvae be picked up: but the rate of increase is actually even greater than it appears, as it has been shown that there is a tendency for the parasites to increase as the *square* of the number of animals per unit area.

With all these forces in favour of numerical increase of parasites one may well ask by what miracle the animals in our fields ever escape parasitic disease. The logical explanation of miracles has always been a stiff proposition, and much of the research work which is being carried on at the present time into the helminthiases of grazing animals may be regarded as an endeavour to explain this one.

Proceeding along the mathematical line, as in the analysis of the effect of overcrowding, we might consider some such unit as a 'sheep-per-acre-week' with a view to easy comparison of the amount of grazing sustained by various pastures: the influence of factors other than the grazing animal and its particular kind of parasites upon an increase of parasite population is so great, however, that a unit such as this would be quite useless for estimating the amount of infection in a field. Indeed, these third factors are of such dominating importance that it is hoped that a thorough understanding of their influence may enable us, some day, to bring the worm diseases of grazing animals under our control.

The 'Third Factors' governing the Increase of Parasitic Worms

(*a*) *Immunity*.—First of all there is the question of immunity, i.e. the resistance of the grazing animal to the development of the infective larvae which it acquires while grazing on infected herbage.

The study of the immunity reactions to worm-infection has attracted much attention among workers in parasitology during the past decade,

and many interesting points have been revealed. In general, it may be stated that adult animals are much more resistant both to the results of worm-infestation and to the actual development of the worms than are immature animals. Although adults are never entirely immune and usually carry a few parasitic worms throughout their lives, their resistance to new infection is very considerable, so that they may be able to graze with impunity under conditions that would lead to fatal disease among susceptible *young* animals.

This resistance is not absolute, however, and poor feeding or a deficient diet, combined with a high rate of intake of infective larvae, will break down the resistance, and severe disease frequently occurs among adult stock under those circumstances.

(*b*) *Regular Anthelmintic Medication for the Destruction of Adult Worms.*—Since we are dealing first with the inhibiting influences upon the parasitic stages of the worms, it will be convenient to make a short mention here of the use of the medicaments known as anthelmintics.

The control of parasitic worms by the use of *cheap, safe, easily administered and effective* drugs is the means of control most favoured by the farmer, who finds the restrictions imposed on him for the control of the parasites by other means most irksome, and difficult to fit in with the management of his stock. At the end of the last century, upon the advice of a South African veterinary surgeon, the farmers there began to use copper sulphate for the control of the 'twisted wireworm', and so saved the South African sheep-farming industry, which was threatened with ruin as a result of the enormous numerical increase of that parasite.

Were it not for regular dosings with copper sulphate, which is now used all over the world for the limitation of the increase of the twisted wireworm, it would be impossible in many parts to rear sheep. This medicament is the only one yet known for use in grazing animals that answers the requirements of being cheap, safe, easily administered, and effective; but, unfortunately, it only serves against this one species of parasitic worm.

Our knowledge of anthelmintic medication as a means of controlling the worm population and preventing disease is therefore very limited at the present time and, with the exception of the twisted wireworm and one or two other species, we must depend upon other measures for preventing the excessive multiplication of the worms.

(*c*) *Factors Acting upon the Larvae in the Pastures.*—The factors influencing the increase of the parasites next to be considered are those concerning the development of their free-living stages on the ground. These may conveniently be considered under four headings:

1. Factors affecting the *development* of larvae in the pastures.
2. Factors affecting the *longevity* of the larvae.
3. Factors affecting the relative concentration of larvae in the pastures and their *accessibility* to the grazing animal.
4. Factors affecting the *disappearance* of larvae from the pastures.

(1) *Soil moisture* is popularly supposed to have a marked influence, and 'wet' pastures are usually thought to be 'wormy' pastures. There

appears to be no valid reason for this supposition, however, and it may reasonably be argued that 'moist' pastures are just as dangerous as 'wet' ones for the development of diseases caused by nematode worms, the only real difference being between 'moist' pastures and 'very dry' pastures such as occur in arid countries.

Drought produces rather an interesting result in that it inhibits the development of some species of larvae without destroying them, the embryonated eggs remaining viable but not hatching until moister conditions recur. This sometimes leads to the accumulation of a large amount of potential infective material on the pastures during times of drought and a mass release of infective larvae when wet weather appears. This sequence of weather conditions occasionally leads to the widespread appearance of worm disease in apparently epidemic form.

Rain assists larval development by supplying abundant moisture, and although heavy rain washes many larvae off the herbage, they soon climb on to it again.

Frost has no action whatever in destroying the infective larvae, but through inhibiting their development its effects are similar to those of drought in that the accumulation of potential infection is followed by a mass development of infective larvae as soon as warmer weather conditions recur—rather like the sudden invasion of our roads by week-end motorists as soon as the weather decides to be warm.

Trampling of faeces into the soil, such as occurs where sheep are penned together, is distinctly favourable to larval development.

(2) Since the most lethal of the natural forces acting upon the ensheathed resistant larvae is dryness, *the relative moisture of the soil and of the atmosphere* doubtless play a part. Observations made at Weybridge have shown that the larvae which climb high into the herbage may die within 24 hours in dry weather, but those which remain close to the ground retain their vitality for months. The *nature of the herbage* is also of some importance, the longevity of the larvae probably being greater in thick matted herbage which keeps them near to the ground than in a first or second year's grass ley, or in clover where they are able to climb away from the soil and come into contact with the drying influence of the air.

(3) *The amount of herbage* in a field has a marked influence on the number of infective worm-larvae picked up by a grazing animal, an important point which had not been recognized until some observations on the larval-content of pastures were carried out at Weybridge, necessitating the employment of the unit 'larvae per pound of herbage'. It was then realized that the herbage may be regarded as a diluent to the larvae; where herbage is long and plentiful there tends to be a comparatively small larval-content in a rumen full of grass, but where herbage is scarce, as during times of drought, and on many farms during ordinary weather towards the end of the summer, a high concentration of larvae is likely to be contained.

The kind of herbage has an interesting influence upon the accessibility of larvae to the grazing animal, larvae being able to climb more easily on to some kinds of herbage than on to others. The structure of a shoot of

grass, for instance, is such that the greater part of the infective larvae tend to remain near to the soil, being turned off the stem and along the under side of the lower leaves. In clover, however, there is nothing to prevent a venturesome larva from climbing up the petiole and on to the trifoliate lamella of the leaf, and it is there that the great majority are actually found.

This factor is of particular significance where sheep are concerned. The highly selective grazing of these animals is now generally recognized, and it is probable that while picking the better part of the young growth of the grass plants they tend to leave the bulk of the worm larvae behind on the coarse under-leaves; but while in clover, and selecting the green upper part of the leaf, they are taking the part which carries most of the worm larvae.

It is suggested that this may be the mechanism which has led to the increased incidence of parasitic gastritis in Northumberland, following the extensive use of basic slag and the consequent increase of wild white clover in the pastures.

Patchiness of pasture and *time of day* also have an influence upon the rate of intake of infection.

(4) *The duration of a rest from grazing* by infected animals has an obvious influence upon the amount of infective material remaining in a pasture. Observations made at Weybridge have shown, however, that the natural death of the larvae begins almost as soon as they have reached the infective stage, some of those which climb high into the grass being killed within a few hours by the drying action of sun and wind.

A more important consideration, however, is the effect of a rest upon the 'number of larvae per pound of herbage'. This effect may be very great, particularly at a time of the year when the grass is making a rapid growth, and it is probably on account of the growth of grass as much as the death of the larvae that benefit is derived through a rest from grazing.

Manuring with nitrates by forcing a rapid growth of grass to dilute the larvae may produce a similar reduction in the number of larvae per pound of herbage.

Of all the methods employed for the destruction of infective larvae in a pasture, however, doubtless the best is the *eating off of the infective herbage by animals which are unsuitable for the development of the particular parasites concerned.* Larvae which are picked up by the wrong host animal in this way are destroyed, and as an illustration of the effectiveness of the procedure, reference might be made to a certain paddock attached to a public thoroughbred stud which was found to carry some 6,000 'red-worm' larvae per pound of herbage. Each of the several sheep placed there to clear up the infection would therefore collect and destroy some 90,000 larvae daily, which might otherwise remain to infect the horses.

Haymaking is doubtless very effective for the removal of larvae from an infected field.

Ploughing is probably not nearly so effective as is generally supposed, as the plough does not completely invert the soil surface and leaves a

space between the furrows through which it is both easy and natural for the larvae to migrate.

Harrowing can have little effect, and burning of the grass can only be carried out in particularly rough herbage where trouble from helminths is unlikely to arise.

Destruction of larvae through the application of lime, salt, kainit, or other substances to the pasture has little or no effect.

Conclusions

To say that parasitic worms constitute the principal controlling factor in the achievement of maximum animal population through grassland-farming is stating a truth that there can be no denying. On looking into sheep-farming practices—for it is the sheep-farmers who bear the brunt of the loss from parasitic worms—it is surprising to find how many of the age-old procedures of penning sheep, feeding them, and moving them, have their origin in the control of parasitic worms. This reason is, of course, generally unknown to the farmer, who has developed the methods through a long and costly period of trial and error. The oft-repeated adage that 'sheep should never hear the church bells ring twice in the same field' doubtless refers to the period of six or seven days required for the development of the infective larvae on the grass. The closed system of folding sheep over arable land with the movement of the pens every three days, and the farmers belief that sheep which are being folded should never be allowed to 'run back' on to land grazed some days previously, refer to the same factor. The removal of young sheep from rich crowded pasture on to clean land at the end of the summer refers to the accumulation of worm-infection on those pastures, as also does the restriction of the number of sheep to the acre, which is so forward a question in every sheep-farmer's mind, and sets a very definite limit to the profit that can be made out of an acre of sheep land.

It is no exaggeration to say that every good farmer knows almost to a sheep how many his land will carry, and if he exceeds that number in a normal year that they will cease to thrive and may even become diseased and die. It seems quite clear that the evil effects of overstocking and the parasitic disease that is brought on through keeping too many sheep is representative of some flaw in the adjustment of the parasites to the grazing animals, which may be described in popular terms as an upset of the 'balance of nature'. Fortunately for the farmer, the powerful resistance to the development of parasites which the grazing animals ultimately acquire (providing that they do not die in the process) gives this balance a considerable amount of elasticity without which it would be impossible to crowd sheep together, even with the limited success we now attain. The farmer, however, stretches the elasticity of this ecological balance to the very limit in order to make a profit out of his land, and trouble frequently results.

The number of sheep per acre is only *one* of the variable factors in the ecological unit of parasite, pasture, and grazing animal. With one or two rare exceptions a variation in the virulence of the parasitic worms (apart from differences which are peculiar to the various species) is not known

to occur, but a lowering of the resistance of the grazing animal as may be brought about through deficient food, or resulting from the increased susceptibility of a group of animals containing too many immature individuals, are common causes of increased worm-burden. This same result can just as easily be brought about by the derangement of a wise rotation of grazing, or the shortage of pasture and the poverty of its nutritive qualities that often occur towards the end of the summer. What may justly be regarded as reasonable stocking during an ordinary year may constitute overcrowding during a drought. Indeed, the variable factors are very numerous, and there are many small alterations, unknown to the farmer's rule of thumb, which favour an increase of the parasites beyond the broad limits of the natural balance, and disease results.

The loss to the country from these parasites is very great indeed, both from outbreaks of obvious disease and from bad thriving. Figures are difficult to obtain, but I am aware of one farmer who lost between £4,000 and £5,000 as a result of parasitic gastritis during the course of five years' arable sheep-farming, and of 43 sheep-farmers in Kent who, on inquiry, were clearly shown to have lost over £10,000 between them during an epidemic of the disease in the drought of 1933–4.

So long as the farmer stocks his land to the maximum and remains ignorant of the factors which influence the increase of parasitic worms, these losses will continue. Eradication of the parasites is quite out of the question at the present time, so that we must do what we can to control their increase. Recent observations on the factors which lead to this end are distinctly helpful, but the struggle to keep the numbers of parasites down is likely to be a long one, and the danger of worm disease will dog the progress of greater stock production through grass-land improvement until practical methods of eradicating the parasites have ultimately been found.

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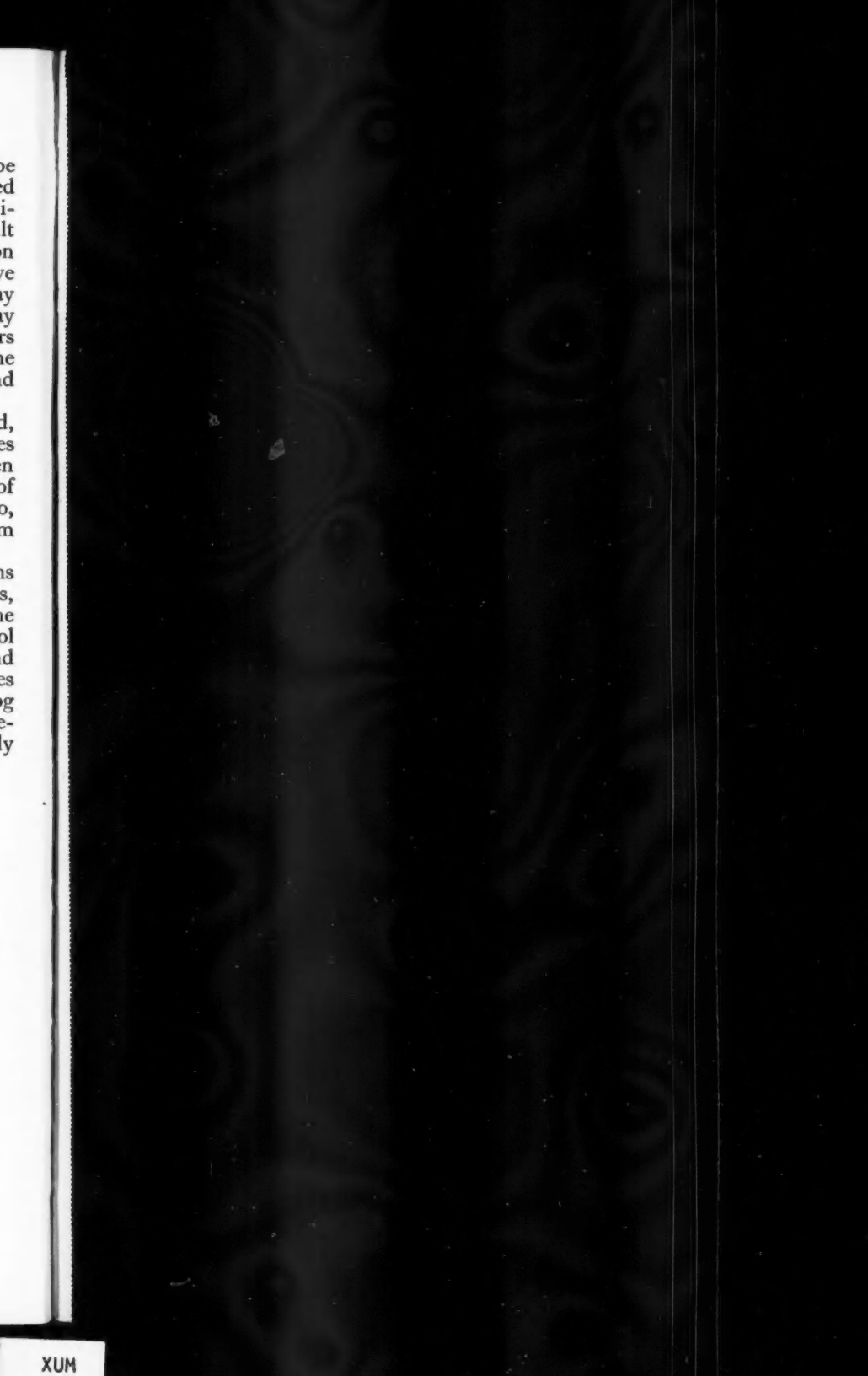
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